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**Southern Forest
Experiment Station**

New Orleans,
Louisiana

General Technical Report
SO-34
1981

Proceedings of the
First Biennial Southern Silvicultural Research Conference

Atlanta, Georgia
November 6-7, 1980

**Edited by
James P. Barnett**

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FIRST BIENNIAL SOUTHERN SILVICULTURAL RESEARCH CONFERENCE

Edited by

James P. Barnett

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Sponsored by:

Southern Forest Experiment Station

Southeastern Forest Experiment Station

Southern Region of the Association of State College and University Forestry Research Organizations

PREFACE

Silvicultural research has been a dynamic force in southern forestry for decades. At the present there is a large group of federal, state, university and industry researchers who are striving to meet the needs of rapidly expanding forestry efforts. Seldom have there been opportunities for those working in the areas of silvicultural research to meet to exchange ideas, coordinate efforts, and establish working relationships. The purpose of this conference was to provide a forum for: exchange among silviculturists, research coordination, continuing education for researchers, review of research in progress, and presentation of new approaches or techniques of general interest.

This first of an intended series of conferences was the outgrowth of coordination meetings between the Southern and Southeastern Forest Experiment Stations that had been held biennially for several years. The late William F. Mann, Jr., suggested at the 1978 coordination meeting that those meetings be replaced by a series of regional conferences that would provide a forum for coordination of research as well as an opportunity for silviculturists to periodically meet. These silvicultural conferences will continue to be scheduled biennially.

Acknowledgements are made to the Conference Co-Chairmen, John W. Henley of the Southern Station in New Orleans, Louisiana, and Walter A. Hough of the Southeastern Station in Asheville, North Carolina, and the Program Planning Committee:

David L. Bramlett, Southeastern Forest Experiment Station,
Macon, Georgia

Tommy R. Dell, Southern Forest Experiment Station
New Orleans, Louisiana

William R. Harms, Southeastern Forest Experiment Station,
Charleston, South Carolina

Klaus Steinbeck, University of Georgia,
Athens, Georgia

George L. Switzer, Mississippi State University,
Starkville, Mississippi

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James P. Barnett
Program Chairman

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SILVICULTURAL RESEARCH--A PERSPECTIVE[1]

Philip C. Wakeley[2]

Abstract. Primitive working conditions and meager financing impeded early silvicultural research in the South. The very newness of the field, however, led to rapid and substantial progress; early workers enjoyed "cream to skim". Further, limited staffing necessitated close personal acquaintance with plant material and much cooperative work, both of which yielded large research dividends.

I have been asked to picture silvicultural research in what may seem to some of you rather primitive times. The main points I should like to bring out are: (1) the importance and value, readily apparent in those times, of the researcher's intimate personal acquaintance with the plant material being investigated; and (2) the dividends from starting some studies on spur-of-the-moment inspiration or to seize a unique opportunity, without prior clearance from the Director, the Washington Office, or the League of Nations.

In the light of today's pay scales and costs, the financing of my own first research certainly was primitive. Four years after the Southern Forest Experiment Station's establishment, I began work there on October 16, 1924, as a Temporary Field Assistant at $70 a month plus field expenses. Twenty-five days later I was given permanent appointment as a Junior Forester at $1860 a year plus actual field expenses. As late as 1934 I was detailed to Washington, D. C. for 2 weeks on a $3.00 per diem. Even after 40 years in the Service I never quite made a $15,000 salary; I retired in 1964 at $14,965 a year.

It wasn't that I was treated badly or discriminated against financially. The Southern Station, the Branch of Research, and the U. S. Forest Service itself were poor. My personal diary for January 21, 1927, reads: "Today's paper reports $4,000 a month alimony granted temporarily to the wife of Charlie Chaplin, movie comedian, pending divorce. That's $48,000 a year. The total appropriation of the Southern Forest Experiment Station, with seven permanent and several temporary men, four clerks, four cars, and nine States to cover, is only $39,800."

Prior to my arrival the Station had no vehicles; staff members had to furnish their own cars. In October 1924 we obtained two Model T Fords, to be shared turn and turn about among nearly a dozen permanent and temporary men. In December 1929 I drove one of those original Fords on a 1,200-mile trip to East Texas to see some nurseries. I averaged 8 miles per gallon and was passed on the open road by a horse and buggy. On my return a dealer allowed us $12.50 on the relic toward the price of the Station's first Model A Ford.

Incidentally, those early cars were risky to drive. Twice my car was vandalized, once in North Carolina by three armed men, and a mile from our installation at McNeill, Mississippi, a Department entomologist was shot and killed for driving a similar car. Those were Prohibition Act days, and many country people thought that the "U.S.D.A." on our license plates stood for "U. S. Dry Agent."

EARLY OBSTACLES TO RESEARCH

Many early obstacles to research were financial, like the shortage of automobiles just mentioned. Although we borrowed sufficient good nursery facilities from the Great Southern Lumber Company at Bogalusa, Louisiana, from 1924 through 1931, my "forestation project" was severely handicapped for several years thereafter by lack of a nursery of our own. We borrowed a little greenhouse space in New Orleans one year for germination tests, but had no Station or Forest Service greenhouse until 1934 or 1935. Despite the importance of our seed storage studies and of temperature control to storage, we had no electric refrigerator till Dr. Carl Hartley, of the Bureau of Plant Industry, assigned one for my use about 1931; my first tests of cold storage were made in my domestic ice box at home.

Our shortage of manpower as a result of meager appropriations was not wholly deleterious. It forced us to "swap work" a good deal, and as a result each of us had a beneficial familiarity with most of the Station's program. Nevertheless, dropping one's own work to help with someone else's too often resulted in starting studies without

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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adequate planning, in working on them at other than the best season, in failing to take some data, or in postponing analysis or publication. In February 1933, for example, Wahlenberg and Gemmer tabulated all the Station's natural-reproduction plots, defined the general and particular purposes for which they had been established, and then rated the plots as having their objects "attained", or as "attainable, possibly attainable, or unattainable." They reported many in the last category "largely because of lack of planning".

Until we got our first business manager in September 1929, the Director, to the detriment of planning and other research functions, had to devote far too much of his time to keeping or verifying and to vouching for all the Station's time and property records and accounts. And it was well into the Thirties before we got an editor of our own and ended the nightmare of being edited by mail from Washington.

The passage of the McSweeney-McNary Act in 1928 and the establishment of the Civilian Conservation Corps--the "CCC"--and other New Deal "alphabet agencies" in and after 1933 went far toward mitigating our financial and manpower troubles. By 1936, instead of working alone and virtually without resources, I had four full-time assistants and all the seed supplies, Forest Service nursery space and planting area, day labor, computing help, and supplies and travel money I could use.

There were other than financial obstacles, however.

One was a general assumption, held for several years, that the mild climate of the South would let us work outdoors 9 months of the year and do our office work under fans during the 3 hottest summer months. This assumption led us to take far more data than we could analyze or publish in the time we allowed, and it was decades before we caught up with even our most important work.

Both we and our Washington overhead were untrained amateurs or novices at many phases of administration and procedure--problem selection and analysis, filing, indexing, defining lines of authority. One horrible example will suffice. In 1934 I had to fill in from personal recollection much essential information, such as weather conditions and seedling foliage-development and root length, missing from Hadley's 1924-25 establishment reports on 12 acres of experimental plantations at Bogalusa. He had made out the reports on forms prescribed and required by the Washington Office. The forms had been "edited" by the Station Director in New Orleans and then "annotated" in Washington. In the process, they had been typed in full, recopied, and recopied again (with all four versions carefully preserved) but had never been bound or even stapled. My personal diary for July 24, 1934, notes: "There's short-sightedness and ineptness somewhere in the system that permits such old-maid fussiness, red tape, hindrance, and delay in such an important preliminary phase of investigation as an establishment report--a phase the vital element of which is prompt completion."

A major obstacle to the conduct and completion of planned and scheduled research was the imposition from Washington, usually without warning, of one or another special Service-wide assignment. Our first experience with such assignments was to gather data, following the Mississippi River flood of 1927, for what was ultimately published as 70th Congress House Document 573 on Relation of forestry to the control of floods in the Mississippi Valley. The "flood study" was assigned to us July 6, 1927, and kept every man and girl at the Station occupied, full time and overtime, till August 30 that year. And we were called upon for supplementary information at intervals till October 1928, when I had to take time off to "determine" the total moisture-holding capacity of the forest leaf litter in the lower Mississippi Valley on the basis of less than 4 pounds of litter sent to us by cooperators!

The time it took to write and issue my first major government publication is a good example of the delays caused not only by Service-wide assignments like the flood study, but also by the necessity of continuing one's regular projects without understudies or assistants and of deferring one's regular work to help with projects considered of higher priority.

This publication, Artificial reforestation in the Southern Pine Region, U. S. Dept. Agri. Tech. Bul. 492, was only 114 pages long. It was first proposed to me orally, by Washington Office personnel in April 1929, when our first experimental plantations were only 6 years old. It was discussed further in November 1929, when I was expected to submit a first draft, within a year, for revision. I jotted down the outline for the bulletin on my own time, at home, on January 25, 1930.

Maintenance of my going studies in seed, nursery, and planting, some work on the "Capper Report" (imposed by Washington), 6 months full time in 1931 and intermittent time thereafter on fire data from Bogalusa for the Director, and more than 2 months in 1932 on the "Copeland Report" (for Washington) all interrupted work on the bulletin. By January 1933 I had only a third of the publication drafted and office personnel had not typed all of that.

The first draft was more than 2 years overdue in Washington. In desperation I offered a recent high-school graduate five cents a half page, double-spaced elite type, to take the rest of the text at dictation and type it up. In 2 weeks I dictated all the rest of the bulletin to her at night, in overtime and at my own expense. By June 8, 1933, I had revised her typing, had a fair copy typed at the office, and had added some completed and some skeleton tables and graphs. We submitted the manuscript to Washington on June 8, 1933, and after a tedious 2-1/2 years of editing and rewriting, the finished bulletin (dated November 1935) came off the press in January 1936. Despite disparaging comment on the bulletin from the Washington Office, the rapidly expanding CCC planting program on the southern National Forests and in several southern States resulted in the practically complete exhaustion of the first printing (3,000 copies, as I recall) in about 3 weeks. A second printing was eventually issued.

Two other early and very serious obstacles to research require mention.

One of these was a practically profession-wide prejudice against fire in the forest, in any form. When I joined the Southern Station staff in late 1924, Project Pf, "Protection, fire" had the highest priority of our six formal lines of work. (My project, "Forestation", had the lowest.) We wasted unconscionable percentages of our meager funds and manpower laying out plots (often without check plots), measuring fire scars, tallying dead seedlings, and taking photographs to "prove" that any and all fire was "bad", instead of the numerous different things that fire actually did. And in several studies, including one very expensive one, we contrasted annual burning with complete exclusion of fire, without ever considering the possible effects of periodic fires.

It was the early or mid-Thirties before a number of circumstances (including my own 1931 study of various burns in the longleaf pine type at Bogalusa) opened our eyes to the potential benefits of prescribed burning. In this field, H. H. Chapman and Herbert L. Stoddard were years ahead of us.

The other major obstacle was our well-nigh universal lack of grounding--at the Southern Station and in Washington--in statistical theory and techniques.

Not one of our Station staff had had any statistics in college. Among the old 1912 to 1914 thinning plots that we had inherited and all plots of all kinds that we had laid out ourselves from 1921 through 1927, there was no single instance of replicated treatment!

A few of us younger men had misgivings in the matter and were buying books--the Station library had none on the subject--and were trying to learn something about statistics by ourselves. I was stimulated by Donald Bruce's comment in April 1926 that "no germination tests he had so far heard of had any sound statistical basis" and that enough similar samples or replications would "permit checking by the method of standard deviation." On March 5, 1928, I laid out the Station's very first replications, five apiece of two soil disinfectants and their untreated checks in our borrowed nursery beds at Bogalusa, and 6 weeks later laid out ten 1-milacre spraying-plot replications and ten 1-milacre checks in dense longleaf reproduction, also at Bogalusa.

In June 1928 L. I. Barrett and I started a staff seminar in statistics, but it never amounted to much. The real break came with Roy A. Chapman's return to the Station in October 1934, after 3 years' intensive training in Washington under Francis X. Shumacher and some priceless contact with R. A. Fisher. Roy revolutionized our experimental design, vastly improved our sampling techniques, taught us analysis of variance, and showed us the immense possibilities in measuring interactions. (In my own work, measurement of interactions sometimes increased by fifty-fold the amount of information obtainable from a given quantity of seed or number of planted trees.) From that time on our publications took on a new cast and, I believe, helped stimulate other Stations to similar progress in statistics.

EARLY RESEARCH ASSETS AND INCENTIVES

Although "trading work" to offset the meagerness of our staff did interrupt our individual studies, as noted under OBSTACLES TO RESEARCH, it did, as also noted there, give us a breadth of information and perspective not always enjoyed by researchers in later, more affluent times.

During my early years on the Southern Station staff a growing interest in the southern pines and later in commercial planting and in the Station's whole program of research brought many of the professionally great to our territory. As the most junior member of the staff I often drove the Model T Ford while a distinguished visitor talked shop with the Director on the back seat or rode in front with me to see better. Later I frequently served as the main guide for such visitors in many different places, but especially over the commercial plantings and natural reproduction and our own experimental plantations and other plots at Bogalusa. The facts and principles learned and the stimulus derived from these visitors[3] were beyond price.

---

[3] For the record, they included Dr. George Sudworth of check-list fame, W. W. Ashe, Associate Chief Forester Earle Clapp, H. H. Chapman, Austin Cary, Walter Mulford, Eloise Gerry, Raphael Zon, and Extension Forester W. R. Mattoon, and also Wild Life Specialists Aldo Leopold and H. L. Stoddard. Among our most distinguished foreign visitors up to 1936 were Tor Jonson, Henrik Hesselman, H. G. Champion, and Dr. Franz Heske.

By no means all our help, however, came to us from professionally trained men. We were thrown into contact with, and came to know and appreciate, a host of keenly observant and highly intelligent foremen and day laborers in many phases of commercial forestry work.

Much of the nursery information in my Tech. Bul. 492 and guiding later studies came to me from the Great Southern Lumber Company's nursery foreman, Kenzie Knight. He was an ex-convict with only a second-grade education, but his knowledge of southern pine nursery stock and soils and weeds and other pests was phenomenal.

Milt Miley, a Great Southern planting- and fire-crew foreman, had a little more schooling. He taught me much about the Nantucket tip moth and helped directly with some of my life-cycle caging experiments. (He knew what the moths were because he had tied his wife's dish towel over some infested twigs and "made her wipe the dishes with her apron till the moths come out.")

My own most valuable informant, however, was F. O. ("Red") Bateman, Chief Ranger of the Great Southern Lumber Company, who, in the short space of 12 or 13 years, developed the basic method of planting southern pines still in use today, supervised the successful planting of 28,500 acres, and (even more remarkable) obtained abundant natural reproduction of longleaf pine on 45,000 acres. Although he had had no formal technical training, and indeed had not completed high school, I still consider Red, as I wrote in the Journal of Forest History (1976. 20: 2, 91-99) to have been one of the greatest silviculturists the South has known.

We owed much to a succession of temporary field and laboratory assistants, who contributed many original observations and important suggestions as well as vast amounts of high-quality routine work. Some of these temporary employees later acquired permanent appointments, like Roy Chapman, whose contributions in statistics I have already mentioned, and Mary L. Nelson, whose work with seed made her the best team-mate I ever had in the forestation project.

We owed much of our early progress to our cooperators. The Great Southern Lumber Company at Bogalusa gave us nursery space, planting and other study areas, quantities of seed, occasional work crews, and the coverage of their fire-protection system, and other companies also gave us substantial help. From 1934 on, Region 8 of the U. S. Forest Service assisted our forestation research immensely with nursery and planting space, CCC and other manpower, quantities of seed, and some outright funding. Many State foresters extended similar cooperation to a lesser but still important degree. The Bureau of Plant Industry in Washington (especially through Dr. Carl Hartley), the Forest Products Laboratory, several schools of forestry, and the Boyce-Thompson Institute of Plant Research all helped us with technical information and in some instances with laboratory services.

The essence of cooperation is mutual interest, a free exchange of information, and goodwill. The present Council Tool Company planting bar is a case in point. Over the years the company developed it from an original design by Red Bateman at Bogalusa, with the help of A. D. Read of the Long-Bell Lumber Company (who first added the step), three CCC enrollees (who inspired the substitution of the "T" for the original "D" handle), and myself, who worked out the most efficient dimensions of blade and handle.

INTIMATE ACQUAINTANCE WITH PLANT MATERIAL

In the early days, each of us in charge of a main line of work had to share each stage of investigation with the few understudies or assistants we had, if indeed not carry it out entirely alone. In my case, for example, I collected, extracted, dewinge and made germination tests of most of my own seed; grew, counted, measured, dug, and packed my own seedlings; and helped plant my own trees and then examine and measured them annually for the first 5 or 10 year in the field. The resulting intimate acquaintance with our plant material was one of our greatest asset in our early research.

By 1926 we were aware that the Nantucket pine tip moth, *Rhyacionia frustrana* Comst., caused serious damage to young planted loblolly and shortleaf pines. I believe it was in the fall of that year that Dr. Tragard, a visiting Scandinavian entomologist, opined that the insect must have a 2-year life cycle. This I could not believe, because I had found overwintering pupae in the tips of 10-month-old loblolly pine seedlings in the nursery. To prove my point I began, on planted trees, a series of caging experiments that ultimately proved that in southern Louisiana the tip moth had four generations a year (1935. So. Forest Exp. Sta. Occas. Paper 45, 8 pp.).

In my annual remeasurements of trees in experimental plantations, it had grown upon me not only that all young southern pines were multinodal, but also that the first internode formed each year was distinctly longer than the later ones. This observation led, ultimately, to the concept of the "five-year intercept" technique for evaluating site quality in stands less than 20 years old (Wakeley, 1954. Proc. Third Annual Forestry Symposium, School of Forestry, La. State Univ., pp. 32-33. Wakeley, P. C. and Marrero, Jose. 1958. Jour. Forestry 56: 332-336, illus.).

In 1932, in the process of thinning an overdense natural stand of longleaf pine seedlings for Dr. L. J. Pessin, then Field Assistant Linc Ellison noted that the needle fascicles of small longleaf seedlings might be either 2-needled or 3-needled, instead of consistently 3-needled as the text-books said. He called the phenomenon to my attention and later published a paper on it. In turn, I subsequently discovered that when longleaf seedlings infected with brown spot needle blight regressed from the 3-needled to the 2-needled habit, they were usually past saving by spraying with fungicide. Thi finding was of direct value in scheduling the spraying or prescribed burning of longleaf pine plantatio

Laboratory Assistant Mary L. ("Polly") Nelson's epoch-making discovery of the role of light in the germination of southern pine seeds arose from similar intimate acquaintance with plant material. She was running germination tests on "mats" of moist acid peat in square glass dishes with plain glass lids, 1000 seeds per test in four dishes holding 250 seeds each. Because of lack of space she was stacking the dishes four deep, and soon noticed that the seeds in the top dish germinated sooner and more completely, sometimes far more completely, than the comparable seeds in the three dishes below. By further tests she proved conclusively that differences in light accounted for the phenomenon. She published the results in the ephemeral Southern Forestry Notes No. 41, 1940, and they were soon picked up and quoted all over the world. The technique used at the Macon Seed Laboratory traces back directly to her finding.

SPUR-OF-THE-MOMENT STUDIES

During my first 10 years at the Southern Station I and others often learned more from studies undertaken on our own initiative, from sudden inspiration, and not approved in advance by higher authority, than we did from regularly scheduled major efforts prescribed by the Director, various advisory bodies, or Washington overhead. To keep the record straight, let me say that we usually fitted such studies into gaps in regular scheduled work, with little or no extra travel, and that we carried many of them out on "contributed"--that is, on unpaid--overtime.

For example, Hadley, under whom I did my first planting at Bogalusa, had been directed to study spacings of slash and longleaf pines, and fall versus spring planting, dibble versus mattock planting, and pruned versus unpruned roots of these two species and loblolly pine. In December 1924 we laid out 12 acres of Great Southern Lumber Company land for these studies. When we had fitted all the prescribed tests into the layout, we had an acre and a half left over. Hadley said "What shall we do with them?"

I was less than 2 months on the job, but, in measuring seedlings for Hadley in some of his nursery tests, I had been greatly impressed by variations in size, foliage, and degree of dormancy of the seedlings in even the best and most uniform beds. I said "Let's compare first- and second-grade seedlings and cull seedlings of slash and loblolly pines."

We did, and, except for the spacing tests, the grades were the only treatments we put in that winter that produced any significant differences in survival or growth. With some refinements made during the next few years, those initial seedling grades developed into those still in use today.

Again, H. H. Chapman's 1922 publication of "Sonderegger pine" as probably a loblolly X longleaf hybrid, plus my own discovery of Sonderegger seedlings in the longleaf pine seed beds at Bogalusa, led me to try to authenticate the cross by making it artificially. Controlled application of loblolly pollen to bagged longleaf "flowers" in 1928 and 1929 failed, but controlled application of slash pine pollen to longleaf "flowers" in 1929 yielded a fine lot of hybrids. I understand that some of them are still growing in the arboretum at Placerville, California. E. J. Schreiner, in U. S. Dept. Agri. 1937 Yearbook Separate 1599, 1938, has described them as only the third or fourth authentic artificial pine hybrids, and certainly the first such southern pine hybrids, ever made.

Both in EARLY RESEARCH INCENTIVES and in INTIMATE ACQUAINTANCE WITH PLANT MATERIAL I have already mentioned studies of the life cycle of the Nantucket tip moth. I conceived these studies personally and independently. They were unapproved in advance, carried out entirely in connection with other travel, and done almost wholly on contributed time. My wife made the cages required out of cloth I paid for myself. The studies not only placed our knowledge of the insect itself in correct perspective but yielded me two fairly widely quoted publications and a pleasant trip (though at tourist rates, to be sure) to the Fourth International Entomological Congress in Ithaca in 1928.

One of my first assignments at the Southern Station was making germination tests of pine seed already stored 1 or more years in "paper, sealed wax paper, or sealed glass", both with and without prior sterilization with formaldehyde solution. In 1924 and for several years thereafter, all correspondence from Washington continued to stress container and sterilization tests, apparently on the assumption that infection by micro-organisms or contact with the air might be causing the serious to complete deterioration within 1 year that characterized the seed of all species.

Memories of my college course in plant physiology led me to wonder whether storage temperature might not have some effect. Negotiations with Boyce Thompson Institute in 1927 led to trials of storage at 25°-30° F., with room-temperature checks, and in 1928 I tried storage at about 55° F. in my ice-box at home. The results were revolutionary; we found we could keep even the sensitive seed of longleaf pine viable for several years.

A number of further leads made Polly Nelson and me turn our attention to the effect of seed moisture content on keeping quality. We stored seed of several species at a wide range of moisture contents both under refrigeration and at room temperature, and found that, of the two, low seed moisture content was even more important than low temperature (Mary L. Nelson. 1938. Southern Forest Expt. Sta. Occasional Paper 78, 19 pp.). Seed of one 1931 slash pine lot I had stored at low temperature and by chance at low moisture content still germinated 69 percent after 45 years.

To conclude, intimate acquaintance with one's material and some freedom to do things with it on impulse certainly paid off--in dollars and cents, and in good, clean fun besides.

SILVICULTURAL RESEARCH - CURRENT APPRAISAL AND RESEARCH NEEDS [1]

F. Bryan Clark [2]

Abstract.--The need for and challenge of silvicultural research in the South is great. Projections for forestry research needs in the South suggest a 66-percent increase in silvicultural research by 1985. It is important to choose priorities carefully, coordinate our efforts, and take full advantage of opportunities to cooperate.

Phil Wakeley has provided a picture of the history of silviculture research. My goal is to provide a picture of silvicultural research in the future.

Silvicultural research has center stage in the South. The soils, climate, topography and the inherent growth potential of the tree combine to form conditions for excellent growth. So much so that southern forests are expected to produce half the Nation's wood products needs by the year 2000, and, at the same time, provide quantities of livestock forage, clean water, wildlife habitat and recreational opportunities. Southern timberlands have been producing 30 percent more pine sawtimber than has been harvested. Yet, the average acre of forestland in the South is capable of growing two or more times than present. The South offers a unique challenge to forestry research because most of the gain in forest goods and services must come from small, nonindustrial ownerships that control 72 percent of the forest land base. It is essential that we give serious thought and positive attention to problems that keep these lands from growing more wood faster.

Obviously to meet future demands for forest goods and services and still produce the needed timber supplies, we must increase timber production per acre. In the South, this translates into the culture of about 70 pines and hardwoods. Adding to the challenge of meeting these objectives is the need to foresee and provide practical answers to new problems. For example, insect and disease control measures will become more important as intensive management increases. Wildfires will become more costly as forest investments rise and plantations of genetically improved trees are established. Maintenance of soil productivity and water quality will demand higher priorities for future research, as will impacts for wildlife and recreation usage.

Forestry research efforts continue to be closely coordinated and jointly planned through a system of regional and national planning groups sponsored by the U. S. Department of Agriculture. The Forest Service research program undergoes regular assessment in cooperation with the state Agricultural Experiment Stations, forestry schools, and research users. Research priorities change as new technologies develop and as new regional and national problems arise.

I am sure that most of you have been involved in past planning efforts. The RPA Assessment and Program documents (1980); Pine Reforestation Task Force Report for Southern Forests (1977); Report of the Forest Resources Task Force for Long-Range Planning in Timber Management, "Forest Resources Research Needs in Timber Management," (1974); Intensive Culture on Industrial Forest Lands and Future Wood Supplies; Trends, Expectations, and Needs - a report prepared for TAPPI (1976); A research Development and Application Plan, "Improved Use and Management of Eastern Hardwoods" (1980); and the

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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Southern Region Reference Document - National Program of Research for Forests and Associated Rangelands (1977) are major cooperative efforts. I have used this last document as a basis for these comments. Its sponsors and the sponsors of this conference are the same.

Projections for forestry research needs in the South suggest a 66-percent increase in the timber management research program by 1985. This is more than double projected increases for other research program areas.

A review of the program of this conference provides a good picture of current southern silvicultural research priorities and direction. As we move into this conference remember this--to a great extent the success of forestry progress in the South will depend upon the research priorities and directions decided upon now. Recent data on southern forests predicted supply and demand situation, coupled with analyses of economic opportunities, should stimulate a strong sense of urgency in all of those engaged in research and development.

We need to refine much of the data obtained by early silviculturists not because of any lack of ability on their part, but because of the more intensive forestry being practiced in the South. For example, more complete utilization results in less nutrients being left on the land, and site productivity may be adversely affected by these and other current management techniques. Harvesting, site preparation, and competition control methods are certainly much different than past practices, and probably are adversely impacting the sites. If so, how do we ameliorate.

Modeling growth and yield data for the southern pines is an active research area and will receive more attention. Such work must be extended to include genetically improved, intensively cultured stands. And we will need to determine species performance on drastically disturbed sites such as those resulting from coal mining operations.

We need to develop both even-aged and uneven-aged timber management strategies with emphasis on mixed pine-hardwood types to meet the needs of the small, private owners.

While pine will continue to receive considerable research attention, we cannot meet the South's overall land management and production goals without significant advancements in hardwood silviculture. This opens up entirely new vistas for maintaining and improving bottomland hardwood stands that are shrinking each year due to agricultural encroachments and for utilizing low-grade hardwoods on sites where pine would be more productive. Rehabilitation of degraded upland and mountain forests will be necessary to meet demands for large, high-value hardwoods now in short supply.

Some obstacles to progress in silvicultural research described by Philip Wakeley are likely to continue, but there have been tremendous changes and improvements. With all of the needs of our society we will not have all of the resources we could use to work on important problems in a timely fashion. That's why it is so important that we choose priorities carefully, coordinate what we are doing and take full advantage of opportunities to cooperate.

In summary, southern silvicultural research is alive and well. The need is real and the future is bright. The program for this conference is very ambitious and very impressive. You have a lot to share with each other and thousands of others who are not here. You have a personal responsibility to use the information that will be included in the Proceedings. Your job is not done until this information is put into practical use. And as Phil said it's "clean fun besides."

PLANTATION SURVIVAL STUDIES OF CONTINENTAL FOREST INDUSTRIES[1]

G. Kenneth Xydias[2]

Abstract.--A variety of studies were installed to identify reasons for poor survival and stocking noted in young plantation. These studies failed to show any consistent relationship between survival and the factors of type of lifting, seedling care between lifting and planting, seedling grade, or planting care. However, each of them affected survival in one or more locations. These studies suggest that all phases of a planting program must be emphasized for that program to be successful.

INTRODUCTION

The regeneration program of most pulp and paper companies in the South is characterized by intensive site preparation with mechanical equipment, followed by either hand or machine planting of genetically improved seedlings. This is an expensive system, but it is thought to provide for a greater probability of establishing a new stand and one with narrower stocking variation, than what might be expected if reliance were placed on natural regeneration.

Failure of the system to perform according to expectations may occur as a consequence of unavoidable factors such as an extended drought before the seedlings become established or because of a variety of preventable factors. These include low seedling vigor perhaps due to disease or lifting damage in the nursery, improper handling in the field, inadequate site preparation, or improper planting. There is little that can be done if weather is the major reason for poor survival, but man-caused problems are preventable, and must be identified and corrected.

Continental Forest Industries, a subsidiary of The Continental Group, Inc., and formerly known as Continental Can Company, controls approximately 1.5 million acres of forest land in the piedmont and coastal plain of seven Southern states. This land base is divided into four woodlands districts, each of which provides raw material protection for a pulp mill. These four districts site prepare and plant a total of approximately 34,000 acres of land each year. Most of this acreage is planted with loblolly pine (*Pinus tadea* L.), although a few thousand acres in north Florida and south Georgia are planted with slash pine (*Pinus elliottii* engelm. var. *elliottii*).

Seedlings for the reforestation effort are obtained entirely from company nurseries. One large nursery is situated near Statesboro, Georgia, and provides the seedling requirements for both the Augusta and Savannah districts. Two smaller nurseries, one situated near Chester, Virginia, and the other near Hodge, Louisiana, provide seedlings for the Hopewell and Hodge districts respectively.

Evidence that the regeneration program was not completely successful was obtained from the 1977 inventory of company land. An examination of permanent inventory plots situated in plantations younger than thirteen years old revealed a consistent and similar trend in all four districts. Stocking and survival was generally constant for plantations established prior to the early 1970's, and then began to decline for the more recently established plantations. The long-term consequences of this trend are uncertain,

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

[2] Author is Division Research Forester, Continental Forest Industries, Box 8969, Savannah, Georgia.

Appreciation is expressed to the numerous field personnel who were responsible for the installation and measurement of these studies, and to Messrs. M. A. Steigerwalt and R. E. Tucker for suggestions and advice in the design phases.

t the important points are that the lowered ocking level reduces management alternatives, d implies that the job is not being correctly rformed.

METHODS

A two pronged approach was initiated ring the 1978-79 planting season in an attempt identify factors contributing to the declining ends in stocking. The first approach was to stall several different replicated studies signed to test the effect of specific treat- nts. Treatments considered were mechanical fting in the nursery, tree care between lifting d planting, planting supervision and care, etc. e goal here was simply to identify problem eas for further study. The second approach volved installation of about 275 permanent ots in 'representative' areas of newly estab- shed plantations. These plots could then be ed to determine why individual trees died, and provide clues as to where poor survival was problem. Each of these studies can be briefly scribed as follows:

Lifting and Time of Planting (one location for each of two nurseries)

In this study, trees were both machine fted with a single-row lifter and hand lifted six different times during the planting season. nd lifting was done carefully in order to eserve as much of the root system as possible. anting sites were selected to represent the oughty end of the soil moisture range under e assumption that if machine lifting contributed poor survival by breaking the fine roots, the fects of this damage ought to be more pronounced the drier sites. Outplanting of each lifting thod was replicated six times in a split plot sign, with lifting date forming the whole plot. ch subplot consisted of ten trees from either fting method.

Special Handling and Planting (20 locations)

This study was designed to identify phases the plantation establishment system that might ntribute to poor survival and to provide leads r further study. The specific phases and their jectives are as follows:

Lifting - Compare hand lifting vs. machine lifting.

Transportation and storage - Compare seedlings brought directly to the site against those being used by operational planting crews.

Planting - Compare operational planting with 'special' planting or planting in such a way as to hopefully maximize survival.

These six treatments were laid out in a randomized complete block design with five replications and fifteen trees per plot.

An additional set of treatment plots were installed to compare survival between the operational planting in the study plots and the operational planting of the adjacent area. The distinction here is that in the former situation, the planting crew was aware that they were participating in a study, while in the latter situation they were unaware that a study was being done. Any difference between these two treatments could be attributed to the effect of field supervision. These are referred to as treatment 6 and treatment 7 plots respectively.

The planting for all locations of this study was done during the middle of the dormant season to minimize possible interactions between treatments and the degree of seedling dormancy. The planting sites were variable, but were selected to represent the conditions that might be encountered in any one district.

Grading Trial (one location for each of three nurseries)

This study was established to determine if there is a survival difference between the morphological seedling grades and ungraded trees. The ungraded treatment was included as a check against the possibility that the grading process caused some survival reduction. The study design was also a randomized complete block with five replications of a fifteen tree plot. Each installation was established on 'adverse' sites under the assumption that if seedling grades were determinants of survival, their effect would be more pronounced on these sites. Planting was done in the middle of the dormant season.

Post Mortem Study

This study was established to provide (a) detailed information about why individual trees died, and (b) a data set to test hypothesis about site or management factors associated with survival. It consisted of two series of about 70 permanent plots in each district established over a wide range of conditions. Information gathered for each plot includes dates of significant management activity, i.e., cutting, preparation, planting, etc., characterization of the site, and for the second series, a description of the conditions at planting.

Each planting spot was numbered sequentially, flagged in the field, and its condition described with respect to associated vegetation. If the planting spot contained a tree, a variety of information was collected. This included tree condition (healthy, unhealthy, or dead), reason for its condition, judgements as to its size, position after planting (vertical, horizontal, etc.) and depth of planting. The first series was initially observed in April and May, 1979 or about one to three months after planting, and then again during the dormant season following one year's growth. A second series was also installed in the 1979-80 plantings, but will not be observed until early 1981.

Data Analysis

During the 1979-80 dormant season, trees in each study were characterized as being healthy, unhealthy or dead. Unhealthy trees were those that would probably die, but could not be called dead since they had a few live needles on them. Analysis of the replicated studies was based on the number of healthy trees in each plot. A first step in the analysis was to identify aberrent plots, or those whose survival was such that its probability of occurrence was less than one percent. This was done by assuming that survival in each study was distributed as a binomial, and then determining the probability associated with the number of trees in plots suspected of being aberrent. Aberrent plots could either be deleted or retained in the analysis. The data set in which aberrent plots had been deleted can be referred to as an edited data set and is the one on which the following results are based. However, inclusion of the aberrent plots had relatively little effect.

RESULTS

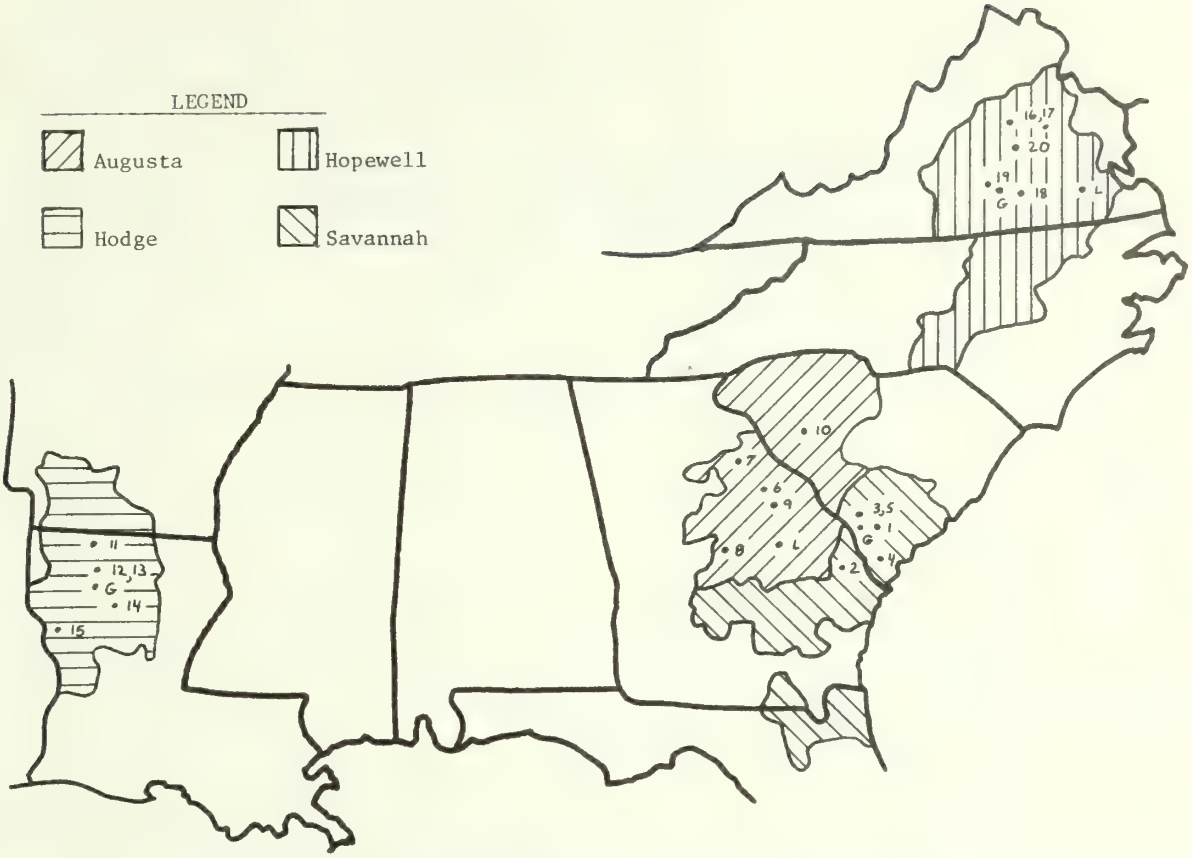
The geographical distribution of the study sites and of the landholdings of Continental Forest Industries is shown in figure 1. The location of the post mortem plots are not shown specifically, but they are distributed throughout the ownership. A summary of the results from the lifting and time of planting study is presented in Table 1. Analysis of variance suggests that the differences in survival between machine-lifted or hand-lifted trees at either location studied were not significant even at the twenty percent level. There was also no interaction between type of lifting and date of planting. Survival tends to decline with planting date, but this is not significant. The last planting at the Virginia location had poorer survival than the earlier plantings.

Results of the special handling and planting study are summarized in Tables 2 and 3. Table 3 shows the survival for those treatments that had a significant difference, and for the entire study. It is assumed in Table 2, that if the observed difference between any comparison has less than a sixteen percent probability of occurrence, then this difference represents an effect of the treatment and not chance variation. The higher level of significance seemed appropriate because of the generally good survival that occurred that year.

Table 3 provides the survival for the significant treatments and for each study location. A brief summary of the results by treatment are as follows:

> Lifting There was no difference in survival between hand and machine lifted trees planted at nine Coastal Plain sites. This agrees with the lifting and time of planting study. However, the survival of machine lifted trees was about five to ten percent less than hand lifted trees in five of seven piedmont sites. This occurred with seedlings from two different nurseries and is an area that should be explored in more detail.
>
> Transportation Seedlings brought directly to the planting site had significantly better survival in five of the twenty trials. Survival differences were not large however, and ranged up to twelve percent.
>
> Operational planting vs. research planting Differences occurred in only two of the 18 trials in which this treatment was installed. (Treatment 7 vs. treatment 6). If the survival of the operational planting in the planting chance (treatment 7) is compared to that achieved by all treatments in the study (treatments 1-6) this increases to four trials or a little over twenty percent. The point to note here is that while operational crews may be more conscientious about their work when putting in a study or simply because they have been chosen to do something different, there is little evidence that the study areas were planted with any more care than the remainder of the tract.

Results of the grading trials are shown in Table 4. None of the treatment means differ significantly with the exception of the Louisiana location. There, grade 3 seedlings had poorer survival than the other grades or ungraded control (P=0.01). Since these seedlings are culls and are normally discarded, this difference is of no practical significance.



igure 1. Land ownership and location of plantation survival studies. Study identifications are: = grading, L = lifting and 1-20 = special handling. Post mortem plots are at various locations within haded areas.

able 1. Survival for Lifting And Time of lanting Study

. Type of Lifting

	Location	
	Georgia	Virginia
Hand	97	88
Machine	95	88

. Date of Lifting

Georgia		Virginia	
Date	Survival	Date	Survival
12/4/78	97	12/11/79	93
1/3/79	98	1/11/79	92
1/23/79	96	1/30/79	91
2/21/79	98	3/11/79	88
3/13/79	93	3/22/79	88
3/29/79	92	4/19/79	74

lthough analysis of the post mortem plots is till incomplete, some results can be briefly ummarized:

- The 1978-79 planting season was an excellent one for survival with a median survival ranging from 85-90 percent depending upon the district. (See Table 5). This survival from operational planting is consistent with that achieved by the special handling and other studies.

- Most mortality occurred between the time the area was planted and the plot was observed. That is, if a tree survived the planting shock, it did not die at a later date.

- Trees that did survive the planting shock but subsequently died tended to be large in size or poorly planted. Deep planting tended to confer a survival advantage, while trees that were planted shallower than normal or were slanted did not survive as well.

- There was no evidence of widespread insect, animal or disease problems. These factors were important on a few plots, but on a district or area basis, the principle reasons given for unhealthy

Table 2. PROBABILITY LEVELS ASSOCIATED WITH SIGNIFICANT TREATMENT EFFECTS.*

		SAVANNAH					AUGUSTA					HODGE					HOPEWELL				
	Comparison	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Operational Check	7 vs 6	–	–	2	–	–	–	–	–	–	–	–	–	7	–	–	–	–	X	X	–
	7 vs 1-6	–	6	1	–	–	13	–	–	–	–	3	7	1	–	–	–	–	X	X	–
Main Effects	Lift	–	–	–	–	–	12	13	–	–	7	X	X	X	X	X	3	–	–	12	–
	Transport	4	–	–	–	1	9	–	–	–	1	–	1	–	–	–	–	–	–	–	–
	Plant	–	–	–	–	–	–	13	–	–	–	–	6	–	–	–	–	–	–	–	11

* Dashed lines in any cell indicate that the probability of observed differences in treatment averages is greater than 15%.

* X's indicate that the treatment comparison was not done.

or dead trees was 'planting' or 'unknown'.

- There were more skips or missed planting spots with machine planting than with hand planting. A median value for machine planting is twelve percent in contrast to one percent for hand planting. In five percent of the cases, however, skips exceeded thirty percent for machine planting and fifteen to twenty percent for hand planting. (See Table 5)
- Planting rates vary within and between districts. The median rate was 700 trees for the Augusta district and 620 trees for the other districts (Table 5). Nominal tree spacing varied from 4-10 feet and nominal row spacing ranged from 8-13 feet.

DISCUSSION

A basic premise underlying all of these studies was that survival would exhibit an interaction between environmental factors and seedling care. That is, the only treatments that would have a high survival rate in adverse years or on adverse sites would be those in which the seedlings were treated properly. Mistreated seedlings would simply die. In good years, it was anticipated that even poorly treated seedlings would exhibit a high survival rate.

The 1978-79 planting season apparently was an excellent year as evidenced by the high median survival rates and narrow survival range shown in Table 5. This survival exceeded the 60-70 percent range that company personnel thought was typical of operational planting in prepared sites. Additional evidence of a favorable year came from the post mortem study. It revealed that trees which were so poorly planted that they were lying on the ground did not die if they were alive at the time the plot was observed.

The special handling studies clearly showed that there was no one factor that was consistently related to poor survival. Instead survival seems to be related to conditions that are unique to the site. For example, mechanical lifting seemed to be important at special handling study location number 16, the transportation system at locations 5, 10, and 12 and operational planting at location 3 and 13. This suggests that attempts to improve survival by stressing a single factor are likely to have only a modest effect. All parts of the regeneration system are equally important, and errors made in one part cannot be corrected at a subsequent step.

Many of Continental's field personnel felt that the mechanical lifter was causing considerable damage to the seedlings and adversely affecting survival. Although mechanical lifting has been shown to be detrimental to survival (Barnard 1980) there was little evidence of it here. The nursery supervisors of the two

BLE 3. SURVIVAL BY TREATMENT AND STUDY LOCATION.

		SAVANNAH					AUGUSTA					HODGE					HOPEWELL				
Comparison		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
erational Planting vs	Trt. 7	-	-	78	-	-	-	-	-	-	-	-	-	83	-	-	-	-	X	X	-
	Trt. 6	-	-	89	-	-	-	-	-	-	-	-	-	91	-	-	-	-	X	X	-
Study Planting	Trt. 7	-	88	78	-	-	93	-	-	-	-	67	79	83	-	-	-	-	X	X	-
	Study	-	94	94	-	-	97	-	-	-	-	78	85	95	-	-	-	-	X	X	-
fting	Hand	-	-	-	-	-	99	91	-	-	95	X	X	X	X	X	97	-	-	87	-
	Machine	-	-	-	-	-	93	84	-	-	88	X	X	X	X	X	89	-	-	81	-
ransport	Direct	99	-	-	-	100	99	-	-	-	88	91	-	-	-	-	-	-	-	-	-
	Normal	95	-	-	-	95	96	-	-	-	78	-	79	-	-	-	-	-	-	-	-
anting	Special	-	-	-	-	-	-	84	-	-	-	-	82	-	-	-	-	-	-	-	82
	Normal	-	-	-	-	-	-	90	-	-	-	-	78	-	-	-	-	-	-	-	94
Study Average		98	94	91	96	98	97	87	95	89	86	75	84	93	99	76	92	90	97	86	88

shes indicate that treatment comparisons were non-significant (p 0.15).
s indicate that treatment not installed.

ble 4. SUMMARY OF THE GRADING TRIALS.

	Seedling Grade				
cation	1	2	3	-	Average
rginia	94	95	89	89	92
uth Carolina	65	67	67	71	67
uisiana	93	88	72	83	84

mpany nurseries where machine lifting is used, wever, point out that machine lifting is capable causing a great deal of seedling damage.[1] If e machine is operated at a relatively slow forward speed and the belts are properly adjusted, then little damage will occur. However, attempts to increase production by increasing the ground speed or lifting rate will damage the seedlings. This study demonstrated that Continental's nurserymen are using the lifting equipment properly.

One use of the post mortem data is to test hypothesis about the relationships of specific practices to survival. As an example of such a test, consider the question of whether there is a survival difference between plantings done by company and contract planters. Respondents to the Southwide APA plantation survival survey expressed the opinion that survival from contract planters was inferior to that of company crews (Weaver 1980). The post mortem plots provide the data to test this opinion. It turns out that in the Hodge and Hopewell districts, the only districts that do sufficient contract and company planting to justify such a test, that there is no significant difference in average survival between company and contract crews. This is reinforced

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Personal communication; J.P. Neal and T.W. eetland, Nursery Supervisors, Continental rest Industries, Statesboro, Georgia and ester, Virginia respectively.

TABLE 5. PERCENTILE DISTRIBUTIONS FOR VARIOUS PARAMETERS.

Parameters	District	Percentile						
		5	10	20	50	80	90	95
Spots (Trees/Acre)	Savannah	600	615	635	700	810	875	905
	Augusta	625	680	725	825	940	1,035	1,100
	Hodge	480	510	555	650	750	840	900
	Hopewell	450	500	550	650	740	800	875
Trees (Trees/Acre)	Savannah	495	515	540	620	720	750	800
	Augusta	500	550	600	700	875	970	1,025
	Hodge	450	500	535	620	720	820	890
	Hopewell	375	420	480	620	770	810	850
Skips (Machine) (%)	Savannah	2	3	5	13	22	28	32
	Augusta	1	3	5	11	18	21	28
	Hodge	0	1	2	6	12	16	20
	Hopewell	0	0	0	2	8	12	15
Skips (Hand) (%)	Savannah	-	-	-	-	-	-	-
	Augusta	-	-	-	-	-	-	-
	Hodge	0	0	0	0	3	6	7
	Hopewell	0	0	0	2	10	16	20
Survival (%)	Savannah	66	76	82	91	96	98	99
	Augusta	72	80	88	94	97	98	99
	Hodge	78	84	88	94	97	98	99
	Hopewell	46	54	70	85	95	97	98

by the special handling study which suggests that there was generally no difference in survival between the closely supervised study plots and the operational plantings. In addition, there is little difference in the survival distributions between the Savannah and Augusta districts even though the former district was planted almost entirely by contract crews and the latter district by company crews. The point here is that there are good and poor planting crews, and this is largely independent of whether they are company or contract crews.

The post mortem study also showed a fallacy in attempts to determine survival with any degree of accuracy one or more years after planting. Survival by definition is the number of live trees expressed as a percentage of the number planted. The number planted cannot be estimated by assuming that planting is being done at some constant rate or that gaps observed in a row of trees one or more years after planting represent dead trees. Although skips only averaged about twelve percent for machine planting and was much lower for hand planting, they could range as high as 20-30 percent (Table 5). Accurate estimates of survival require that the number of trees planted is known. This can only be done by a post planting cruise to determine planting rates or by the establishment of permanent plots in each planting chance on which both planting and mortality rates can be determined.

One possibility for the declining trends in stocking which Continental noted on their permanent inventory plots is simply that we have been tending to plant fewer trees/acre. This is consistent with our response and probably that of forest industry as well, to the deteriorating economic conditions of the 1970's. That is, attempts were made to reduce costs in all areas of the regeneration program. This included such things as reducing site preparation inputs, consolidation of site preparation activity with attempts to prepare sites when administratively convenient, and elimination of hand planting crews to correct skips and poor planting of machine planted trees. In addition, the sites being prepared during this period generally tended to be the more difficult sites.

The question that remains unanswered is the extent to which the favorable weather masked handling and other problems. Would the slight survival differential observed in a few of the replicated studies be repeated in an adverse year but with overall survival at a much lower level, or would this survival differential be enlarged with only the properly handled seedlings having a good survival? This question cannot be answered until the replicated studies are repeated in an adverse year. In the meantime, a prudent course of action is to simply recognize the fact that all facets of the regeneration system are equally important, and that stressing a single facet is likely to do little to improve the overall survival picture.

LITERATURE CITED

Barnard E. L., C. A. Hollis, and W. L. Pritchett 1980. A comparative evaluation of seedling quality in commercial forest nurseries in Florida. SE Area Nurs. Conf. IN PRESS.

Wakely P.C. 1954. Planting the Southern pines. USDA Agric. Mono. No. 18 233 pgs.

Weaver G. H., B. Izler, F. S. Broerman, and G. K. Xydias, 1980. Preliminary report on the 1979 American Pulpwood Association pine plantation survival and nursery practices survey. SE Area Nurs. Conf. IN PRESS.

LONGLEAF PINE SEEDLING SURVIVAL STUDIES[1]

by J. Andrew Parker and L. Wayne Haines[2]

Abstract.--Effects of needle clipping, clay root dips, and refrigerated storage on survival of longleaf pine (Pinus palustris Mill.) seedlings from four nurseries were studied in southwest Georgia. First-year survival of unclipped seedlings ranged from 4% to 85%, although seedlings were similar in external characteristics. Average survival was 88% for clipped seedlings from the two best nurseries. Overall, needle clipping increased survival 12 percentage points and clay root dips reduced mortality from exposure. Sixty-five percent of clay-dipped seedlings survived 80 minutes of drying in full sunlight. Seventy-four percent of seedlings survived when outplanted after 31 days of refrigerated storage in sealed bags.

INTRODUCTION

The Great Southern Lumber Company planted longleaf pine during the 1920's (Spencer 1979, Wakeley 1969). The species has been planted on a limited scale throughout the South since then, but planting failures have been common. Shoulders and Walker (1979) reviewed the results of 113 planting trials of four pine species planted between 1954 and 1958 in Louisiana and Mississippi. First-year survival results were reported as follows: loblolly (P. taeda) 77%, slash (P. elliottii) 69%, shortleaf (P. echinata) 78%, and longleaf 54%. Landowners often plant loblolly or slash rather than longleaf because they believe the latter is more difficult to regenerate (Mann 1969).

The North Carolina Forest Resources Division and T. R. Miller Company have recently shown that longleaf can be successfully planted operationally (Goodwin 1978, Moody 1978). During the past several years International Paper Company has successfully established longleaf plantations in south Alabama, but elsewhere failures have outnumbered successes. International Paper expanded its longleaf pine research efforts in 1978 with the objective of learning how to fully utilize the species in its intensive forest management program. This paper reports early efforts to improve survival of 1-0 seedlings planted at Southlands Experiment Forest (SEF) near Bainbridge in southwest Georgia.

METHODS

Seedlings from four nurseries (coded A, B, C, and D) were lifted, packaged, and transported to SEF under the supervision of the senior author. Seedlings were graded, dipped, clipped and repackaged at SEF in an enclosed shed. All studies were conducted with seedlings carefully graded to root-collar diameter ≧ 12 mm and dibble-bar planted.

Plantings were established in February 1979 on disked sites and soil moisture was favorable for tree development. Predominant soil series of the study sites were Lakeland, Eustis, and Wagram. Plots were 100 m² and contained 50 marked seedlings. Survival was determined during the fall of 1979 and an analysis of variance was used to evaluate individual studies. Treatment differences were determined by Tukey's test at the 95% level.

Treatments tested in separate studies were: (1) needle clipping, (2) refrigerated storage, and (3) clay dipping and root exposure. Needle clipping consisted of cutting needles to a length of 13 cm just prior to planting. Seedlings were stored at 1°C for 1, 10, 17, and 31 days in sealed kraft paper seedling bags. Moist peat moss was used as a packing medium and the bags were inspected for holes before storage. Seedlings wit oots dipped in a thick kaolin clay slurry were ompared with non-dipped seedlings for periods f 0, 20, 40, and 80 minutes in full sunlight. Air emperature was 12°C and wind velocity estimated t 7 km per hour during the exposure period. ll treatments were replicated either five or six mes in complete randomized blocks.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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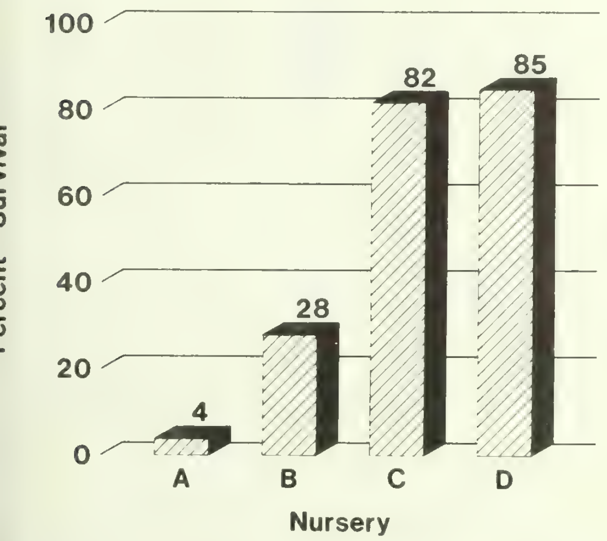
RESULTS AND DISCUSSION

Survival Comparisons

Seedlings in control plots were used to comare survival by nursery source. These were nclipped and undipped seedlings that had not een unnecessarily exposed to sunlight. Survial ranged from 4 to 85% by nursery source fig. 1). This wide range was completely unexpeced because of the care given the seedlings from me of lifting to outplanting. Futhermore, all eedlings were planted by the same crew within even days after lifting.



igure 1.--First-year survival of untreated and unclipped longleaf pine seedlings from four nurseries.

Survival checks of operational plantings using he same nursery sources revealed obvious survial differences and support observations on the esearch plots. Plantings with seedlings from ursery A failed while plantings from C and D ere successful.

The survival differential could have resulted rom nursery management, seed source, or both. ursery visits during the growing season revealed bvious differences in needle length, methods of eed control, and seedlings/m^3. Later, when the seedlings were graded, the percentage of undersized plants varied by nursery. Brown-spot disease was not recognized as a problem with any source. Physiological quality of seedlings probably varied by nursery. Wakeley (1954) discussed seedling quality and physiological quality and observed that morphological grades and physiological quality do not necessarily coincide. Thus, even when only grade 1 seedlings are planted, nursery management can impact survival.

Provenance studies have shown longleaf survival and growth varies with seed source (Snyder, et al. 1977). The four nurseries are located in Alabama, Georgia, Louisiana, and South Carolina. Some are state operated and others are private. Some nurseries obtained local seed while others purchased their seed and the source was unknown. Thus, seed source was a factor that cannot be separated from nursery management differences in this study.

Foresters should be aware that longleaf survival can vary greatly by nursery and should record nursery source on their planting records. Nurseries growing seedlings that fail to survive should be informed of the problem. Futhermore, foresters should avoid such nurseries when obtaining seedlings.

Needle Clipping

Effects of needle clipping on survival were studied with seedlings from nurseries A, C, and D. Clipping increased survival of all sources by an average of 12 percentage points (fig. 2). These results generally agree with those reported by Allen (1955) and Allen and Maki (1951). However, a strong treatment-nursery interaction was evident in this study. Sources C and D which survived well without clipping (79% and 78%) were improved by 8% and 10%, respectively. Survival of source A seedlings was very poor without clipping, but increased 19 percentage points with clipping. These results reinforce the idea that differences in physiological quality probably existed among nursery sources. Increased survival from clipping was attributed to reduced moisture loss from a smaller needle surface area.

Refrigerator Storage

Nursery D seedlings were used in the refrigerated storage study. Storage up to 31 days did not significantly reduce first-year survival but a downward trend was observed after 17 days (fig. 3). This study indicates that high quality dormant seedlings can be held up to three weeks in sealed bags @ 1°C with little loss of viability. Other studies have shown a drop in longleaf survival following seven days of storage in open buildings (Allen 1955, Slocum and Maki 1959, White 1978).

These results are important because regeneration operations need the option of storage to avoid problems associated with bad weather that adversely affects lifting or planting. Futhermore, knowing that longleaf seedlings can be stored successfully, foresters can address other possible causes of planting failures.

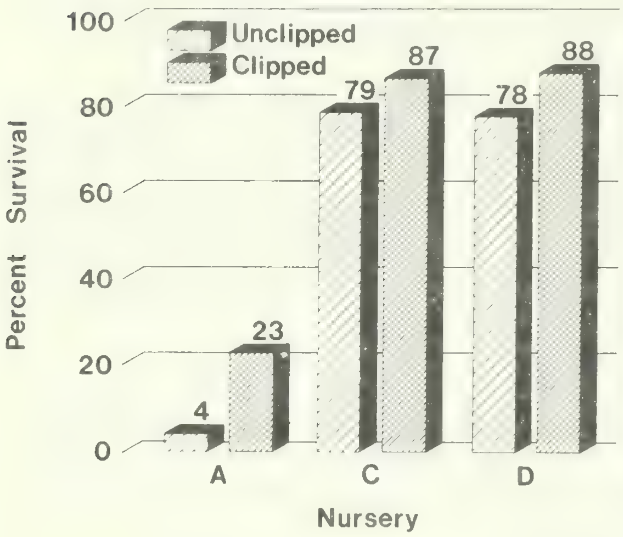


Figure 2.--Effects of needle clipping on first-year survival of longleaf pine seedlings from three nurseries.

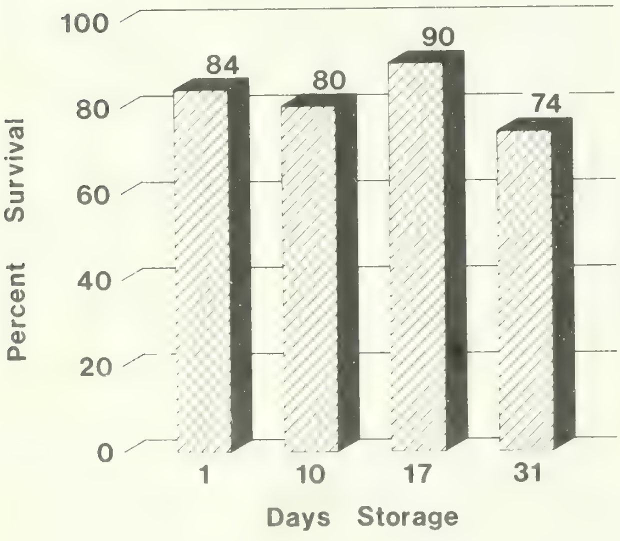
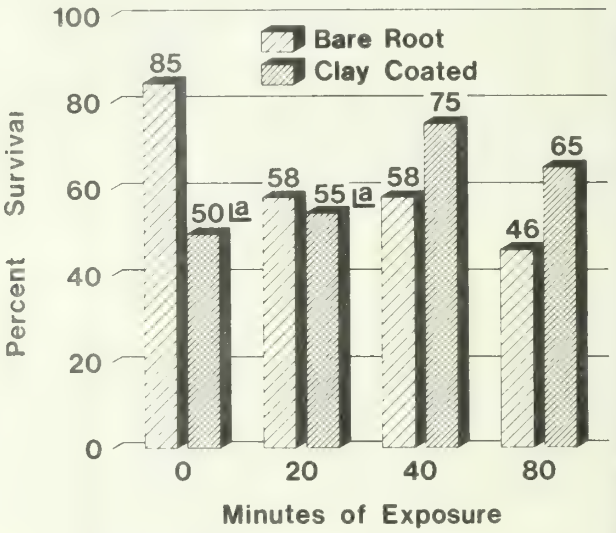


Figure 3.--First-year survival of longleaf pine seedlings after 1, 10, 17, and 31 days of refrigerated storage.

Clay Dipping

The clay root dip study was compromised when seedlings from nurseries A and C were inadvertently mixed; however, the results are reported because they show encouraging trends. Undipped seedlings from nursery C were exposed for 0, 20, 40, and 80 minutes. Clay-dipped seedlings of the same source were exposed for 40 and 80 minutes, but some source A seedlings were used for the dipped 0 and 20 minute comparisons. Thus, the comparisons for exposure periods of 40 and 80 minutes, that show survival increases of 17 and 19 percentage points are valid (fig. 4). The dipped and undipped comparisons shown for 0 and 20 minutes of exposure are invalid because of seedling source differences.



a/ Survival was lower than expected due to a nursery source mistake.

Figure 4.--First-year survival of longleaf pine seedlings with bare and clay-coated roots after 0, 20, 40, and 80 minutes of exposure.

This information and other research shows that longleaf pine seedling survival can be enha by clay dipping their roots (Slocum and Maki 19 Wakeley 1954). This practice should be used wh exposure of seedling roots is anticipated.

SUMMARY

Longleaf survival can vary greatly among nursery sources even when only grade 1 seedlin are planted. In this study the differences amon nursery sources may have been due, at least in part, to seed source differences. Thus, additio research is needed to learn more about the effec of nursery management on seedling survival.

Needle clipping enhanced survival, but the degree of improvement varied with nursery sour. Clipping had the greatest impact on the source that otherwise had very poor survival. Seedlin urvival with exposure was improved by dipping oots in a clay-slurry. This treatment should be sed where planting activities are likely to result n roots being subjected to drying conditions.

Longleaf seedlings store well when sealed in aper bags at 1°C temperature for as long as hree weeks. Proper storage combined with eedle clipping and root dipping, when necessary, hould enhance survival potential of seedlings xcept when nursery management results in poor hysiological quality.

LITERATURE CITED

llen, R. M.
1955. Foliage treatments improve survival of longleaf pine plantings. J. Forestry 53: 724-727.
llen, R. M. and T. E. Maki.
1951. Foliage treatments reduce early mortality of longleaf pine planted on adverse sites. J. Forestry 49:115.
oodwin, O. G.
1978. Progress made in North Carolina in planting longleaf pine. p. 12-23. In W. E. Balmer (ed.) Proc. Longleaf Pine Workshop. Mobile, AL, 17-19 Oct. 1978. USDA Tech. Pub. SA-TP3.
lann, W. F., Jr.
1969. At last - longleaf pine can be planted successfully. Forest Farmer 28(6):6-7, 18-19.
loody, C. W.
1978. Welcome. p.1. In W. E. Balmer (ed.) Proc. Longleaf Pine Workshop. Mobile, AL, 17-19 Oct. 1978. USDA Tech. Pub. SA-TP3.
houlders, Eugene and F. V. Walker.
1979. Soil, slope, and rainfall affect height and yield in 15-year-old southern pine plantations. USDA Forest Serv. Res. Paper SO-153. 52 p.
locum, G. K. and T. E. Maki.
1959. Exposure of longleaf pine planting stock. J. Forestry 57:825-827.
nyder, E. B., R. J. Dinus, and H. J. Derr.
1977. Genetics of longleaf pine. USDA Forest Serv. Res. Paper SO-33. 24 p.
pencer, Jim.
1979. Long live the longleaf. Amer. For. 85 (10):20-23, 64-65.
akeley, P. C.
1954. Planting the southern pines. USDA Agric. Monograph No. 18. 233 p.
akeley, P. C.
1969. Results of southern pine planting experiments established in the middle twenties. J. Forestry 67:237-241.
hite, J. B.
1978. Longleaf pine survival influenced by seedling size and length of storage. p. 26-29. In W. E. Balmer (ed.) Proc. Longleaf Pine Workshop. Mobile, AL, 17-19 Oct. 1978. USDA Tech. Pub. SA-TP3.

THE EFFECT OF WRENCHING AND PLANTING DATE ON THE SURVIVAL OF LOBLOLLY SEEDLINGS[1]

Charles R. Venator
and
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Abstract.--Outplanted undercut nonwrenched loblolly seedlings survived as well as seedlings wrenched every 21, 33, or 45 days. In a replicated planting, survival was roughly equal for seedlings planted in central Louisiana and southwestern Arkansas for the dates November 15 and January 15. However, survival of the March 15 planting was less in Louisiana. Wrenching did not alter seedling morphology nor did it increase lateral root development.

Root wrenching of *Pinus radiata* seedlings has been a common nursery treatment for more than 50 years in New Zealand (Goudie 1935). Wrenching, in combination with undercutting and lateral root pruning, improves survival of early lifted and planted seedlings. The increased survival of seedlings lifted in early winter is an important aspect because large planting programs depend upon lifting and planting prior to the onset of winter (van Dorsser and Rook 1971).

Wrenching is preceded by undercutting of seedlings. This cuts the tap root and initiates new lateral roots. About 4 weeks after undercutting, the first wrenching is done by pulling a tilted (20° from horizontal) spring steel blade under the seedling bed. The blade operates off a lobed cam which is designed to cut a 10 cm sideways stroke. During the sideways stroke the tilted blade travels forward about 4 cm. The reciprocating action permits the blade to pass under the seedlings without pulling them down into the beds (van Dorsser and Rook 1971).

The popularity of root wrenched nursery seedlings is also related to the change in seedling morphology. Undercutting and wrenching inhibit height growth, but root growth is relatively unaffected on a dry weight basis (Benson and Shepherd 1977). Thus, wrenched seedlings have a higher root-shoot dry weight ratio. Wrenched seedlings also tend to have a more fibrous root system and better mycorrhizal development than nonwrenched seedlings. Other morphological changes resulting from wrenching are a smaller shoot, more secondary needles, and greater needle cast on the lower stem (Rook 1971).

Wrenching operations should begin when seedlings reach the desired height for field planting. The initial wrenching is done at a below-ground depth which will stop height growth and at a time when climatic conditions are favorable for seedlin growth. If the seedlings are undercut too early, they will not reach a plantable size and if they are undercut too late, they will not respond to root wrenching because they will have passed the optimum season for photosynthesis. Another important aspect of wrenching is to develop a regime that will maintain the desired shoot/root morpholo A monthly wrenching regime is best for *P. radiata* seedlings.

An optimum nursery root pruning regime has no been developed for loblolly pine, although recent tests have indicated that this species may also benefit from wrenching (Tanaka et al. 1976). This report describes results of a test designed to compare the effect of different wrenching regimes on morphological characteristics of loblolly pine nursery seedlings and the survival of seedlings lifted in early, mid- or late-winter.

MATERIALS AND METHODS

A 240-meter section of a typical loblolly nur ery bed at the Weyerhaeuser Corporation forest nursery in Magnolia, Ark., was selected for this study. Bed density was approximately 290 seedling per square meter. The entire bed was undercut at approximately 18 cm on August 13, 1979, when the seedlings were approximately 20 cm tall. This was

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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nsidered to be a baseline treatment and from
is date the following wrenching treatments were
ne for randomly assigned 15 m plots. Each of the
ur treatments was replicated four times within
e 240 meter bed. The treatments were: a) con-
ol seedlings that were undercut once, but not
enched; b) seedlings wrenched every 21 days;
seedlings wrenched every 33 days and d) seed-
ngs wrenched every 45 days. The individual
ots were separated by a 0.3 m strip where the
edlings had been removed. This cleared strip
s used as an area to insert or remove the
enching blade.

Prior to the first wrenching on August 13,
seedlings were pulled from each of 15 randomly
lected sample points in the center section of
e nursery bed. Their mean root collar diameter
s 2.8 mm and their mean height was 19.9 cm.
ge row seedlings were not included in this sample
order to obtain an unbiased estimate of the
erage seedling in the nursery bed.

Wrenching intervals were adhered to, except
en a scheduled wrenching fell on Sunday. In this
se the seedlings were wrenched on the following
nday. The wrenching blade was set to operate at
cm below soil surface. This depth was main-
ined throughout all wrenchings and periodic
ecks during wrenching indicated blade depth was
ose to 12 cm. The seedlings were lateral root
uned in mid-August and early October.

Immediately following each wrenching the
edlings including the controls were watered to
oid tip wilt and possible dieback of the succu-
nt, tender tips which frequently occur follow-
g extensive loss of the root system as a result
root wrenching. Because of an unexpected out-
eak of *Phomopsis* mainly on the tallest seedlings,
e entire seedling bed was top pruned to 25 cm
early September. Only a few seedlings were
tually top pruned since most were smaller than
cm. Root collar diameter, height and dry
ight measurements were taken from a 0.3 meter
ction across the individual plots prior to
dercutting on August 13 and at each lifting
te. Every seedling lifted in this sample was
asured. The seedlings were hand lifted by
dercutting again to sever new tap root growth.
fter lifting, seedlings were wrapped in canvas,
ken to nursery tables, and graded to remove
all, diseased, broken and malformed seedlings.
ly seedlings with a 3 mm or greater root collar
ameter were retained. All of the seedlings had
condary needles. After grading they were placed
kraft-polyethylene bags and their roots sprayed
th a kaolin clay slurry. All seedlings were
tored at 2° C until outplanted.

Seedlings were lifted on November 15,
anuary 15, and March 15 and outplanted the
ollowing day in central Louisiana and south-
estern Arkansas. Two groups of 50 seedlings
were lifted from each nursery treatment plot and were outplanted for each of these planting dates on each planting site. On the day of planting the seedlings were removed from the K-P bags and wrapped within a moist burlap bag and placed in standard planting trays or bags. They were hand planted at a 0.6 x 1.2 meter spacing. The central Louisiana site located on the Johnson Tract of the Palustris Experimental Forest was bush hogged, burned and disked prior to planting. The soil is a sandy loam and the planting site is flat, but well drained. The Arkansas site, near Murfreesboro, had been recently clearcut, chopped and burned. The soil is a clay loam and the slope is less than 5 percent.

RESULTS

Initial Seedling Condition

After wrenching there was no visual evidence that seedlings suffered serious shock nor was any mortality observed. The seedlings continued to grow, both in height and root collar diameter. There are several references that show wrenching suppresses shoot growth, but all indications in this study show that root growth is not affected adversely. If affected, root growth in this study appears relatively greater, because of the stimulatory effects of pruning on propagation for new roots from the severed tips (Benson and Shepherd 1977; Tanaka et al. 1976).

Treatment Effects on Seedling Morphology

Average height of seedlings before undercutting was 19.9 cm. Seedling height measurements taken on November 15 were as follows: 21.0 cm for the controls; 20.7 cm for the 21 day wrenching regime; 21.0 cm for the 33 day wrenching regime; and 20.8 cm for the 45 day wrenching regime (table 1). These height means were not statistically significant at the 5 percent level. The effect of wrenching on seedling root collar diameter and total number of secondary roots also failed to show any significant differences (table 1). The mean root collar diameter of the control seedlings was 3.7 mm. Mean root collar diameters of the wrenched treatments were 3.7 mm, 3.6 mm, and 3.3 mm, for the treatments 21, 33, and 45 days respectively. These differences were not statistically significant at the 5 percent level. The mean number of secondary roots ranged from 8.9 to 10.1 per seedling. These differences also were not significant statistically.

Field Performance

Seedlings lifted on January 15, 1980, were uniform in morphological characteristics (table 1). Mean root collar diameters ranged from 3.5 to 3.6 mm for the four treatments. Mean seedling heights ranged from 18.9 cm to 20.2 cm, and the number of lateral roots ranged from 8.9 to 9.6 per seedling at treatment. There were no significant differences among the measurements for any of the data in this table.

Table 1.--Mean height, root collar diameter, and number of lateral roots for seedlings wrenched every 21, 33, or 45 days and control seedlings. The first figure is for seedlings lifted on November 15, 1979. The second and third figures are for seedlings lifted on January 15 and March 15, 1980. Means are followed by their standard error.

Wrenching treatment	Height	Root collar diameter	Number of lateral roots
	cm	mm	
Control	21.0 + 0.54 [illegible] ± 0.92 20.4 ± 1.10	3.7 + 0.05 3.6 + 0.05 3.8 ± 0.32	8.9 + 0.13 8.9 + 0.[illegible] 9.4 ± 0.39
21 days	20.7 + 1.06 18.9 ± 0.36 19.9 + 1.08	3.7 + 0.00 3.6 ± 0.09 3.7 ± 0.23	9.5 ± 0.50 9.6 ± 0.16 11.1 ± 0.57
33 days	21.[illegible] ± 1.12 19.6 + 1.37 20.6 ± 1.52	3.6 ± 0.10 3.6 ± 0.16 3.8 ± 0.14	9.8 + 0.51 9.3 ± 0.20 9.7 ± 0.39
45 days	20.8 + 0.48 19.[illegible] ± 0.78 21.5 ± 0.78	3.3 ± 0.11 3.5 ± 0.15 3.9 ± 0.06	10.1 ± 0.27 9.6 ± 0.55 10.1 + 0.72

Seedlings lifted on March 15 followed the same trend with no real difference between treatments (table 1). The root collar diameters of the seedlings averaged 3.8 mm. Mean seedling heights were 20.4 for the control and 19.9, 20.6, and 21.5 cm for 21-, 33-, and 45-day wrenching treatments, respectively. Mean number of secondary lateral roots ranged from 9.4 to 11.1 for the four treatments.

Although the data are not statistically significant there was a slight increase in root collar diameters between November and March. This is probably a normal growth response and not related to wrenching. Height growth did not occur and there was no detectable increase in number of secondary roots between November and March.

By early summer, weather patterns indicated a record heat and drought period. Consequently, we decided to make a preliminary survey in July to assess differences in survival in case the drought continued. The first survey was made on July 1 for the Arkansas planting and July 14 for the central Louisiana planting. The heat wave combined with the dry weather continued until October and for central Louisiana it was considered to be the driest and hottest summer in 50 years. Consequently, seedlings in this study were put to a severe test of survival capability.

Survival for the seedlings planted in southwestern Arkansas was date dependent. On July 1, 1980, 79.5 percent of the seedlings planted on November 15, 1979, were alive (table 2). Seedling survival averaged 95.8 percent for the seedlings planted on January 15 and 95.5 percent for the seedlings planted on March 15. A two-way ANOVA test revealed no statistical differences (5 percent level) in survival due to treatments or planting date for these later plantings. Surviva percentages for this date and for all following dates were transformed to their corresponding arc-sin values for analysis.

Table 2.—Percent survival of wrenched seedlings planted in early, mid-, and late-winter. The seedling survival counts were made on July 1, 1980. The upper figure refers to the planting at Murfreesboro, Arkansas, and the lower figure refers to the planting in central Louisiana. Each mean represents the percent of 400 seedlings originally planted. Means are followed by their standard error.

Wrenching frequency	Planting date Nov. 15, 1979	 January 15, 1980	 March 15, 1980	 $\bar{x}$
		% Survival		
Control	76.5 + 2.77 99.3 ± 0.53	94.2 + 2.02 99.8 ± 0.33	94.6 + 1.61 99.7 ± 0.50	88 99
21 days	81.5 + 4.24 99.5 ± 0.50	97.2 + 0.84 100.0 ± 0.00	93.2 ± 2.70 99.0 ± 0.65	90 99
33 days	78.8 ± 5.07 99.5 + 0.50	95.2 ± 1.51 100.0 ± 0.00	97.2 ± 1.31 99.5 ± 0.50	90 99
45 days	81.2 ± 2.42 98.8 ± 0.65	96.5 ± 1.05 100.0 ± 0.00	97.0 ± 1.46 99.0 ± 0.76	91 97
$\bar{x}$	79.5 99.3	95.8 99.9	95.5 99.3	

In central Louisiana seedling survival was uniform among wrenching treatments and planting dates (table 2). Survival was 99 percent for th control and wrenched seedlings. The lower survival for seedlings lifted and planted in mid-November in Arkansas illustrates that lifting date may be more important for survival in the northern range of loblolly than in the southern range.

A second survival measurement was made in the last week of September and the results refle the drastic impact the long drought had on survival. At the Murfreesboro planting site, survival dropped from a mean of 79.5 percent for the November 15 planting date to 55.5 percent by late September. The seedlings planted on Januar 15 dropped from 95.8 to 67.7 percent survival, while survival of the seedlings planted on Marc 15 fell from 95.5 to 60.1 percent. These survival means between planting dates although ranging from 55.5 to 67.7 percent were not statistically significant at the 5-percent level (table 3). The mean survival between the four wrenching treatments ranged from 59.5 to 62.5 percent and likewise these differences were not statistically significant at the 5-percent level

Statistical analysis of the seedlings plant in central Louisiana also revealed that by late September overall survival was significantly lower. Mean survival between seedling treatments ranged from 54.3 to 59.7 percent but ifferences among means were not statistically ignificant at the 5-percent level. However, a wo-way analysis of the data revealed statistical ifferences among the means ($p < 0.01$) for planting ate. Comparison of the planting date means by sing the Student Newman-Keuls test indicated that eedlings planted on March 15 were statistically ifferent from those planted on the other dates. verall survival was 43.9 percent for this planting date versus 64.8 percent for the seedlings lanted on November 15 and 60.3 percent survival or those planted on January 15 (table 3).

able 3.--Percent survival of wrenched seedlings planted in early, mid-, and late-winter. The seedling survival counts were made on September 30, 1980. The upper figure refers to the planting at Murfreesboro, Ark., and the lower figure refers to the plantings in central Louisiana. Each mean represents 400 seedlings. Means are followed by their standard error. Different letters behind means indicate statistical difference at ($p < 0.01$).

enching: equency:	Nov. 15, 1979	January 15, 1980	March 15, 1980	$\bar{X}$
	% survival			
ntrol	57.0 ± 5.55 67.0 ± 5.92	72.8 ± 5.88 64.5 ± 2.85	57.7 ± 7.96 47.3 ± 8.56	62.5a 59.6a
days	57.8 ± 7.93 64.0 ± 3.82	66.5 ± 6.06 60.8 ± 4.16	57.3 ± 6.24 44.6 ± 4.26	60.5a 56.5a
days	53.5 ± 8.35 62.0 ± 3.61	71.5 ± 4.73 57.6 ± 2.80	60.5 ± 6.37 44.6 ± 3.66	61.8a 54.7a
days	53.5 ± 5.93 65.6 ± 5.37	60.0 ± 4.20 58.2 ± 3.01	65.0 ± 8.94 39.2 ± 4.95	59.5a 54.3a
	55.5a 64.8a	67.7a 60.3a	60.1a 43.9b	

DISCUSSION

Wrenching did not stimulate lateral root evelopment of loblolly pine to the extent reorted for *P. radiata* seedlings. Actual counts f roots for each treatment showed that wrenching id not significantly increase the mean number of ateral roots. Part of the root response to renching could be lost in the lifting operation. lthough particular care was taken in lifting eedlings, some fine lateral roots were unavoidably ost. The loss of fine lateral roots is unavoidble particularly in mechanical lifting operations. hus, until a method is found to save these lateral oots, wrenching may not result in seedlings with ore actual roots after lifting from the nursery eds.

A potential problem of wrenching or underutting is root deformation. The tap roots were ulled or oriented in the direction of the blade ut and consequently formed an L-root configuraion. We do not have any quantitative data on he incidence of this root deformation or of its ffect on performance.

It appears that loblolly as a species has oorer root development than *P. radiata* which has been extensively studied for its response to wrenching. Root regeneration of loblolly seedlings may be significantly different from that of other species. It is also possible that the wrenching plus lateral pruning methods in this study were not sufficiently drastic enough to stress the seedlings.

Some seedling roots grow down the seedling row and avoid pruning. Thus, the seedlings may channelize a larger part of their energy into these unpruned roots. We suspect that most of these long, but small diameter secondary lateral roots are lost when the seedlings are lifted.

Energy for new root growth may preferentially sink into wound healing of severed roots and into existing undamaged (unpruned) roots rather than in the formation of new laterals off pruned lateral roots. Also, it appears that lateral root development is harder to induce along the primary root as this root ages or undergoes differentiation. The optimum zone for new root development probably moves down the tap root and outwards on each lateral root as they grow longer. Repeated severing at 12 cm does not result in a massive development of new tap roots just above the cut root.

Wrenching was not as crucial for seedling survival as was planting date. We are not sure why wrenched seedlings failed to perform better than the nonwrenched seedlings. It may be that the root systems were not stimulated to branch. For whatever the reason, this study did not show any advantage for wrenched seedlings. However, given the results obtained with *P. radiata* we feel that additional tests should be carried out on southern pines to fully explore the potential of wrenching.

The lack of any significant morphological and survival differences between the wrenched and control seedlings may be a result of the single undercutting that the seedlings received on August 13, which was the baseline point for the study. This undercutting may have been sufficient to shock the seedlings and to shut down their growth.

Tanaka et al. (1976) reported that loblolly seedlings, in an earlier wrenching study at the Magnolia Nursery, had many of the characteristics reported for *P. radiata* seedlings. In particular, they were able to detect lower shoot:root ratios, smaller shoot systems and smaller root collar diameters. Survival was also better for wrenched seedlings when planted on a droughty site. Root dry weight was not different from the controls although there were proportionately more lateral roots on the wrenched seedlings than on the control nonwrenched seedlings.

Walstad et al. (1977) reported that wrenched loblolly seedlings had slightly smaller root collar diameters, a slight decrease in shoot length, and moderate increase in the proportion of lateral roots. These changes were suggested in this study, but we were unable to show they had occurred statistically.

LITERATURE CITED

Benson, A. D., and K. R. Shepherd.
1977. Effects of nursery practice on *Pinus radiata* seedling characteristics and field performance. II. Nursery root wrenching. New Zealand J. For. Sci. 7(1):68-76.

Goudie, H. A.
1935. Tree growing in the nursery: the practice and value of wrenching. New Zealand J. For. 3:212-214.

Rook, D. A.
1971. Effect of undercutting and wrenching on growth of *Pinus radiata* D. Don seedlings. J. Appl. Ecol. 8:477-490.

Tanaka, Yasuomi, J. D. Walstad, and J. E. Borrecco.
1976. The effect of wrenching on morphology and field performance of Douglas fir and loblolly pine seedlings. Canad. J. For. Res. 6:453-458.

Van Dorsser, J. C., and D. A. Rook.
1971. Conditioning of *Radiata* pine seedlings by undercutting and wrenching. Description of methods, equipment and seedling response New Zealand J. For. 17:61-63.

Walstad, J. D., J. H. Breland, and J. G. Mexal.
1977. Application of wrenching and lateral pruning in loblolly pine nurseries. Southe Forestry Research Center Technical Report 74-17. Weyerhaeuser Company, Hot Springs, Arkansas.

ECTOMYCORRHIZAL CONDITION OF PLANTED PINES: WHAT DIFFERENCE DOES IT MAKE?[1]

John L. Ruehle[2]

Abstract.--Failure of nurserymen and reforestation specialists to acknowledge the biological importance of ectomycorrhizal development on seedling stock increases the chances for reforestation failures. Although the need for high-quality seedlings is widely recognized, quality often is rated only on aboveground portions. Roots are often mistreated and ignored. Roots are usually monitored only at lifting time, after all factors contributing to their development have occurred. Condition and quality of the seedling root system at planting is of prime importance in survival and early growth. Since ectomycorrhizae increase root surface area, improve uptake of water and nutrients, maintain resistance to adverse soil conditions and provide some protection from damage by feeder root pathogens, ectomycorrhizal development on pine planting stock is a determinant of seedling quality. Factors that influence root system development are also likely to affect ectomycorrhizal development. All procedures from lifting to planting should be designed to retain the majority of the lateral roots and attached ectomycorrhizae.

INTRODUCTION

Although most nurserymen and reforestation specialists producing and planting pines would agree with Zobel (1979) that seedling quality is important, they often fail to agree on a common definition of quality. Nurserymen usually rate quality of seedlings on above-ground portions and too often ignore the roots during the production period. Why? Possibly because in the nursery roots of seedlings are not visible and their development is difficult to monitor. After the seedlings are lifted, some consider top:root ratio, height, fresh weight per 1000 seedlings, and presence of secondary needles and buds as measures of quality; others consider nonvisible internal differences, such as starch levels, percent vascular tissue, and percent moisture, the qualities to rate. All of these factors working in concert undoubtedly influence the capacity of seedlings to survive and grow well after planting. Nurserymen would probably agree that the condition, both physiological and morphological, of the root system of pine seedlings is important, but it would be difficult to obtain a consensus on an optimum root grade (woody and fibrous roots) for survival and rapid early growth of planted pines.

Reforestation specialists also have a general concern for seedling quality. They know that high quality seedlings planted without root deformity on properly prepared sites usually survive and grow well. They often warn planting crews to guard the root systems from drying or exposure to freezing temperatures. However, their main concern during the planting operation is usually the depth of planting and avoidance of root deformity.

Too few nurserymen and reforestation specialists have a working concept of pine root systems and the importance of ectomycorrhizae.

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Most of the feeder roots of pine seedlings growing in a natural environment have abundant ectomycorrhizae--a symbiotic association between mycorrhizal fungi and succulent short roots. This symbiotic association increases root surface area, uptake of water and nutrients, and resistance to adverse soil conditions and some feeder root pathogens.

Wakeley (1954) reported years ago that loss of lateral roots on slash and longleaf pines prior to planting markedly decreased field survival. More recently, Dierauf and Garner (1978) found that severe root pruning of loblolly pine significantly reduced field survival. If significant numbers of third- and fourth-order laterals (the roots supporting ectomycorrhizae) are lost prior to planting, seedlings must regenerate new laterals and form ectomycorrhizae before aboveground growth can start. This regeneration is dependent on the stored food in the stem and tap root. If stress occurs while the seedlings are regenerating new roots, chances for mortality increase.

Wakeley also recognized and reported back in 1954 that ectomycorrhizae are essential to good mineral nutrition of southern pines. Why then is there so little regard today for retaining ectomycorrhizae on pine seedlings prior to planting? Nursery experts tell us that better handling during seedling lifting, storage, and transport is necessary to ensure optimum field survival and early growth of planted pine seedlings. Yet too many, I find today, have little regard for retaining ectomycorrhizae on seedling root systems. Even if pine seedlings arrive at the planting site with adequate numbers of ectomycorrhizae attached to the lateral roots, I find that too many tree planters disregard, or are simply unaware of, the need to retain ectomycorrhizae on plantable seedlings. Tree planters, in an attempt to avoid root deformity during planting, often reshape the root system to accommodate the shape of the hole made by the planting tool--a procedure that causes a significant loss of ectomycorrhizae.

Nurserymen and reforestation specialists know that seedling quality and better handling improve field performance, but they often are less certain how and why these things work. Perhaps one reason the nursery practices employed to produce quality pine seedlings often succeed is that they encourage the development of suitable ectomycorrhizal root systems. Better handling methods in lifting, grading, packaging, storing, transporting, and planting have been developed through trial and error to improve survival and early growth after planting, often with little understanding of the biological mechanisms at work. When these methods are examined from a biological point of view, I believe we will find they work because they provide, among other things, for the retention of viable ectomycorrhizae on the planting stock.

The current consensus of forest scientists is that, with all other factors equal, pine seedlings with abundant ectomycorrhizae at planting survive better and grow faster than seedling with few ectomycorrhizae. Our research results at the Institute for Mycorrhizal Research and Development have reaffirmed this hypothesis. We advocate that nurserymen devise means to protect the lateral roots with ectomycorrhizae during lifting and avoid drying and deterioration of these delicate roots during storage and transpor We further suggest that pine seedlings be plante with the most complete and intact root system possible. The complaint will come from the planting sites--"Seedlings with all these fibrou roots are too difficult to plant." Once we convince the regeneration specialists and their supervisors that the retention of fibrous roots and attached ectomycorrhizae will improve survival and early growth, they will develop the technology to overcome this difficulty.

Since the objective of reforestation with pines is maximum survival and rapid growth of newly planted seedlings and since we know that abundant ectomycorrhizae are essential to this goal, let us consider means of lifting, grading, storing, transporting, and planting pine seedlin that will retain the maximum complement of functional ectomycorrhizae.

BARE-ROOT SEEDLINGS

Southern nurseries rarely have problems producing 1-0 pines with abundant ectomycorrhiz --abundant meaning that over half of all short roots are ectomycorrhizal. Fumigation of nurse soil results in a reduction of both pathogenic and symbiotic fungi. Airborne basidiospores released from naturally occurring ectomycorrhiz fungi in forests adjacent to nurseries usually reinfest the fumigated soil by mid June. Barrin any detrimental cultural procedures, i.e., misu of pesticides, excessive N or P fertilizer applications, or root disease harmful to root develo ment, the pine seedlings will develop abundant ectomycorrhizae by the end of the growing seaso

Root undercutting, wrenching, and lateral pruning induce a more fibrous and compact root system on pine seedlings. In addition to creat seedlings physically adapted to today's plantin techniques, these practices alter root configur tion and create the framework for supporting an increased number of second- and third-order laterals--the roots that support short roots colonized by ectomycorrhizal fungi. Consequent these various manipulations employed to aid the planting operation often increase ectomycorrhiz development.

The manner in which pine seedlings are lifted often determines how many ectomycorrhiza are retained on the seedlings. Years ago, when labor was cheap and plentiful, seedlings were lifted by hand. When properly supervised, this procedure caused little loss of second- and third-order lateral roots. Now we find sophisticated lifting machines being used almost exclusively because they save time and labor. Unfortunately, if the nursery soil is too wet or too heavy, machine lifting can cause dramatic loss of lateral roots and ectomycorrhizae.

Handling of seedlings during packing also causes loss of ectomycorrhizae on pines, especially if seedlings are graded. By omitting the grading prcedures, many nurseries have eliminated excessive drying of roots and the mechanical damage to fibrous roots caused by the additional handling. Seedling storage is usually necessary because most nurseries are too far from planting sites to lift and plant the same day. Modern tree nurseries have adequate refrigerated storage. If seedlings with good ectomycorrhizal development are packaged moist and stored properly at 3° to 5°C, the ectomycorrhizae will survive in an acceptable physiological condition for several months (Marx 1979).

Seedling abuse is probably most common at planting sites. You all have heard your share of horror stories: a seedling shipment is left in the sun to build up damaging heat in the seedling bags; a shipment is unlaoded and left exposed to freezing temperature too long prior to planting. Only too often, after the bags are opened, the roots are allowed to dry out before the seedlings are planted. Tree planters will strip the roots to make it easier to get the seedlings into the dibble hole or planting machine furrow.

Seedling tops may be well hardened-off and resistant to some rough handling, but root systems which have lost contact with soil are very easily damaged. Ectomycorrhizae are the first structures lost during mishandling.

After all this, reforestation specialists are surprised when mortality is 40 percent or more! When I view some of these operations, the mortality causes no surprise, the survival does. These old, clung-to practices, which come from either carelessness, ignorance, or simply complacence, should be modified or eliminated. With better planning, education, and supervision we can avoid practices which undermine quality planting.

CONTAINERIZED SEEDLINGS

If you accept our concept that pine seedlings with well-developed ectomycorrhizal root systems survive and grow better after outplanting, then containerization offers a unique opportunity for putting theory into practice.

Many of the problems mentioned can be avoided by planting properly grown container stock with suitable ectomycorrhizal development. Root pruning is not required with this stock. All roots and ectomycorrhizae developed in the plug are retained and remain intact at planting. Storage is generally no problem since container stock is held in the greenhouse or lath house until shipment time. Although container-grown seedlings are bulky to package and ship, they are usually less perishable than bare-root seedlings. The planting operation is easier because the seedling root system contained in the plug is of uniform size and shape. How can mycorrhizal development be encouraged in containers? Certain practices currently employed for growing containerized pines, such as heavy fertilizer applications and sterile growing media, often discourage ectomycorrhizal development (Marx and Barnett 1974). At the Institute for Mycorrhizal Development, we have developed satisfactory ectomycorrhizae on container-grown pines by altering these cultural practices and introducing selected fungal symbionts.

Ectomycorrhizal fungi are introduced into the growing medium in various ways. Inoculum in the form of duff, humus, infested soil, crushed sporophores, or excised mycorrhizal roots has been used with varying degrees of success. Although these methods normally ensure ectomycorrhizal development if cultural methods are modified, they also create problems. These inoculum forms often lack the most desirable fungi for the tree species and planting sites, and some contain various harmful microorganisms and noxious weeds. Mass production of pure culture inoculum is the best solution. Abbott Laboratories currently produces, for research purposes, a dried inoculum containing vermiculite, peat moss and *Pisolithus tinctorius*. This inoculum yields excellent results on containerized southern pines. This type of inoculum is preferred because it avoids the problems previously mentioned.

Results from some of our outplanting trials with container-grown southern pine colonized with *P. tinctorius* have been encouraging. The greatest improvement in survival and early seedling growth using seedlings tailored with this symbiont is exhibited on coal spoils and borrow pits.

CONCLUSION

Whether we are growing bare-root or containerized pine seedlings, we can say that any ectomycorrhizae on the roots of the planting stock are better than no ectomycorrhizae at all—a conclusion based on 10 years of research at the Institute for Mycorrhizal Research and Development. Certain species of ectomycorrhizal fungi are more important to tree survival and growth under field conditions than other species. Much of our current research effort is aimed at finding the best combination of planting stock and fungal symbiont for a particular planting site.

Many of the points I have made were outlined by Wakely back in 1954. Little has been done since then to improve on *ideas* and *concepts* concerning site preparation, condition and care of seedling stock, and methods of planting as they affect initial survival of southern pines. Wakely also recognized that ectomycorrhizae are essential to good mineral nutrition of southern pines and pointed out that if ectomycorrhizae are lacking during the production of planting stock, inoculation should be tried.

Why, then, you may well ask, have I taken the trouble to mention these points again. Since ectomycorrhizal fungi occur naturally in such abundance in our nurseries and plantation sites, our best nursery stock usually develops luxuriant ectomycorrhizae prior to lifting; seedlings in the plantations become well colonized with ectomycorrhizal fungi indigenous to the site. I see our current nursery and planting programs for pines failing to address the problem of retaining ectomycorrhizae on planting stock and have attempted to convince you that pine seedlings well colonized with appropriate ectomycorrhizal fungi are ecologically adapted to better survive the rigors of outplanting.

Wakeley stated that the most widespread cause of low initial survival in southern pine plantations is not fire, animals, insects, or disease, but drought--drought in the sense of loss of more water from the tops than can be replaced through the roots. He concluded that the ability of planted seedlings to overcome drought and attain high initial survival seemed to depend upon formation of considerable new root tissue promptly after planting. I agree with this conclusion, and wish to add that ectomycorrhizal colonization of new root tissue aids in high initial survival. In fact, our findings at the Institute show a marked improvement in seedling survival if ectomycorrhizae are retained on the seedling roots at time of planting. If droughty conditions exist on the planting site, we advocate tailoring the seedlings with a fungal symbiont ecologically adapted to droughty conditions.

We are developing fumigation, inoculation, and fertilization procedures for tailoring seedlings with ectomycorrhizae synthesized by selected fungal symbionts produced in pure culture. Although these procedures increase the cost of the nursery operation, this cost is easily justified by the improved performance in outplantings. No one can afford to plant pine seedlings that have less than an excellent chance of surviving.

As knowledge accumulates about ectomycorrhizae on pines planted in the South, the options for nursery and plantation management can be better defined. The research task will be complete only when the costs of establishing and maintaining suitable ectomycorrhizae on plantable seedlings are accepted as the price we have to pay for acceptable survival and growth on newly established plantations.

Economists are continually evaluating the effectiveness and cost of various forestry operations--from seed collection to tree harvesting--to give advice about prudent investments for the future. Unfortunately, nursery operations and plantation establishment have not yet received adequate analytical treatment. It seems taken for granted that the technology of growing and planting trees simply exists, take it or leave it, and that the only major technological problem which policymakers are interested in is how to get X number of seedlings planted on Y number of acres. When the analysts get around to the economics of producing and planting pine seedlings, I think they will find that mycorrhizal technology is a pretty good investment.

Much of my presentation is speculative, but the answer to the question in my title is an emphatic "YES! The mycorrhizal condition of planted pines is important." The cost of assuring good mycorrhizal development in the nursery and retaining it until the seedlings are planted is not high. When one considers that the cost of seedlings represents only 8 to 12 percent of the total investment in reforestation, and that even in this juvenile stage the seedlings represent 100 percent of the potential financial return, then the potential benefits of improvements in seedling quality become evident.

LITERATURE CITED

Dierauf, T. A., and J. W. Garner.
1978. Root pruning loblolly pine seedlings effect on survival and growth. Virginia Div. Forest. Occa. Rept. 52.

Marx, D. H., and J. P. Barnett.
1974. Mycorrhizae and containerized tree seedlings. Proc. North American Containerized Forest Tree Seedling Symp. R. W. Tinus, W. I. Stein, and W. E. Balmer, eds. Great Plains Agric. Council Pub. 68.

Marx, D. H.
1979. *Pisolithus* ectomycorrhizae survive cold storage on shortleaf pine seedlings. U.S. Dep. Agric. For. Serv., Res. Note SE-281, 4 p. Southeast. For. Exp. Stn., Asheville, N. C.

Wakeley, P. C.
1954. Planting the southern pines. U.S. Dep. Agric. For. Serv., Agric. Monograph 18.

Zobel, B.
1979. The influence of forestry trends on nursery operations. Proc. 1978 Southern Nursery Conf. U.S. Dep. Agric. For. Serv., Tech. Publ. SA-TP 6.

PISOLITHUS TINCTORIUS ECTOMYCORRHIZAE ENHANCE THE SURVIVAL AND GROWTH OF PINUS TAEDA ON A SOUTHERN APPALACHIAN COAL SPOIL[1],[2]

R. F. Walker, D. C. West, and S. B. McLaughlin[3]

Abstract. A study was initiated to determine the significance of Pisolithus tinctorius ectomycorrhizae to the establishment and growth of loblolly pine (Pinus taeda) on sites disturbed in surface mining operations. Nursery grown seedlings infected with this fungal symbiont were outplanted on coal spoils in Tennessee. Treatments included seedlings infected with a mycelial inoculum of P. tinctorius and fertilized at the rate of 112 kg/ha NPK, control seedlings without P. tinctorius fertilized at an identical rate, seedlings infected with P. tinctorius but without fertilization, and control seedlings without P. tinctorius or fertilization. Seedlings infected with P. tinctorius survived better than control seedlings, but fertilization during the first growing season reduced survival irrespective of mycorrhizal treatment. Infection by P. tinctorius and fertilization resulted in the best seedling growth, while unfertilized control seedlings exhibited the least growth. Unfertilized seedlings infected with P. tinctorius and fertilized control seedlings exhibited growth intermediate to that of the other treatments. It appears that an ectomycorrhizal infection of loblolly pine by P. tinctorius can enhance survival and growth on these adverse sites and reduce the need for fertilization.

INTRODUCTION

Nursery grown pine seedlings have been used in many surface mine reclamation programs in the eastern United States. The adverse growing conditions encountered on these sites, such as low pH, low nutrient status, high concentrations of toxic substances, elevated surface temperatures, and droughtiness have contributed to a generally poor performance by these seedlings. Much research has been directed toward improving artificial regeneration techniques to provide a greater degree of success. The inoculation of seedlings in the nursery with an ectomycorrhizal fungus offers promise as a viable aid in establishing pine on adverse sites.

The importance of ectomycorrhizae to the growth of pine in natural forest soils is well recognized. Many species of ectomycorrhizal fungi infect the roots of pine in normal forest soil environments (Marks and Kozlowski, 1973). Under stress conditions, such as those that often prevail on surface mine sites, certain of these fungi appear superior in their ability to survive and provide benefits to their hosts. Many workers (Hile and Hennen 1969, Lampky and Peterson 1963, Marx 1975, Medve et al. 1977, Schramm 1966) have reported the occurrence of basidiocarps of Pisolithus tinctorius (Pers.) Coker and Couch associated with several tree species on various coal spoil sites. It is logical to assume that P. tinctorius ectomycorrhizae contributed significantly to the survival and growth of these early colonizing host species.

Experimental techniques have been developed to artificially inoculate pine seedlings in the nursery with pure cultures of P. tinctorius (Marx 1969, Marx and Bryan 1975). Inoculated seedlings have been shown to be superior to uninoculated seedlings in the nursery (Marx and Bryan 1975, Marx et al. 1976), on routine reforestation sites (Marx et al. 1977), and on adverse sites (Berry and Marx 1978, Marx and Artman 1979). The evidence suggests that the artificial inoculation of pine seedlings in the nursery with P. tinctorius will promote sufficient ectomycorrhizal development to provide these seedlings a significant advantage over those grown by conventional methods.

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Many coal spoils, including those that are not acid, are difficult to revegetate because they are deficient in one or more of the essential plant nutrients (Vogel 1975). Most mine spoils in the Appalachian region are deficient in plant-available nitrogen and phosphorus (Plass and Vogel 1973). Nitrogen and phosphorus amendments are usually essential for the successful establishment and growth of vegetation on such sites. Several workers (Bengtson et al. 1973, Zarger et al. 1973) have shown the value of fertilization to the survival and growth of various pine species on coal spoils in the southern Appalachians. More recently, Berry (1979) provided evidence that the use of starter fertilizer tablets improved initial growth of loblolly pine on badly eroded sites in the Tennessee Copper Basin.

The study reported here was designed to determine the significance of P. tinctorius ectomycorrhizae to the successful establishment of loblolly pine (Pinus taeda L.) on coal mine spoils in Tennessee. Due to the demonstrated response of pine seedlings to fertilization on these adverse sites, a fertility variable was introduced to allow examination of the interrelationships of P. tinctorius ectomycorrhizae and fertilization as they affect survival and growth. It is believed that an infection of loblolly pine with this fungal symbiont can reduce the need for the application of nutrient amendments on coal spoils in the southern Appalachians.

MATERIALS AND METHODS

The P. tinctorius inoculum used in this study was produced by the Institute for Mycorrhizal Research and Development (IMRD) of the USDA Forest Service 4/ by the methods of Marx (1969) and Marx and Bryan (1975). It consisted of fungal mycelia grown on a vermiculite-peat moss-nutrient media substrate such that the hyphae penetrated between the layers of the vermiculite particles. The inoculum was leached with cold tap water prior to application in the nursery.

The P. tinctorius inoculated seedlings and the control seedlings used in this study were grown by the Weyerhaeuser Company 5/ by the methods of Marx and Bryan (1975). Nursery beds were fumigated with 392 kg/ha of MC-2 6/ three weeks prior to seeding. Fertilizer and lime were applied to the beds at the rate of 560 kg/ha of 10-20-10 and 1120 kg/ha dolomitic limestone. The P. tinctorius inoculum was applied at $1076\ ml/m^2$ of soil surface and incorporated into the bed. Other beds were left to become infested by naturally occurring ectomycorrhizal fungi for the production of control seedlings. Stratified seeds (McCurtain County, Oklahoma seed source) were coated with Arasan 7/ and planted in April, 1977. Three applications of $(NH_4)_2SO_4$ were applied in 2 week intervals at the rate of 112 kg/ha/application beginning in June, 1977. The seedlings were lifted in January, 1978 and graded to a height of 15 cm and a root collar diameter of 3 mm. Ten seedlings were randomly selected from both the inoculated and control nursery beds and evaluated by the IMRD for ectomycorrhizal development. All seedlings were stored at $5^{\circ}C$ for 2 months prior to outplanting.

The outplanting site was a coal spoil located in Campbell County, Tennessee. All mining ceased in the fall of 1977 and the spoil was returned to approximate original contour. A straw mulch was applied and the site was hydroseeded with a mixture of Kentucky 31 tall fescue (Festuca arundinacea Schreb.), perennial ryegrass (Lolium perenne L.), and Korean lespedeza (Lespedeza stipulacea Maxim.). Five replicate blocks, each with four 5x5 m plots, were established on the site. A 6 m wide border separated each plot. One of four treatments was randomly assigned to each of the four plots within a replicate block. The treatments in this random block design were seedlings infected with P. tinctorius and fertilized at a rate of 112 kg/ha NPK, control seedlings without P. tinctorius fertilized at an identical rate, seedlings infected with P. tinctorius but without fertilization, and control seedlings without P. tinctorius or fertilization. Twenty-five seedlings were planted by hand in each plot in five rows of five seedlings each. The spacing of seedlings within and between rows was approximately 1.25 m. Five spoil samples were obtained

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6,7/ The use of these products does not constitute an advocacy of them on the part of the Oak Ridge National Laboratory.

from each plot at a depth of 0 to 20 cm, combined into one composite sample per plot and chemically analyzed. One hundred fourteen g of 15-15-15 fertilizer was evenly distributed over 0.37 m^2 around each of the appropriate seedlings to achieve the fertilizer equivalent of 112 kg/ha NPK.

At planting, measurements of height and root collar diameter were taken of each seedling. Survival, height, and root collar diameter measurements were taken in March, 1979 and March, 1980. Height and root collar diameter growth measurements were expressed as relative growth indices by subtracting the initial measurement from the second year measurement and dividing by the initial measurement. Growth parameters expressed in this manner compensate for initial differences in seedling size and variation in planting depth. Similarly, the plot volume index (PVI) of Marx et al. (1976) was expressed on a relative basis (RPVI) by subtracting the initial PVI from the second year PVI and dividing by the initial PVI. All data were subjected to analyses of variance.

RESULTS

The seedlings inoculated in the nursery with *P. tinctorius* had 15 percent of their feeder roots infected with this symbiont and 17 percent infected with naturally occurring ectomycorrhizal fungi, primarily *Thelephora terrestris* Ehrh. ex Fr. The total ectomycorrhizal infection of the inoculated seedlings was 32 percent, and 90 percent of the seedlings examined were infected with *P. tinctorius*. The control seedlings had 35 percent of their feeder roots infected with naturally occurring ectomycorrhizal fungi, primarily *T. terrestris*. None of the control seedlings examined were infected with *P. tinctorius*.

The chemical analysis of the spoil samples collected at planting revealed that the plots were fairly uniform with respect to most of the parameters tested. The means for all plots were pH 5.0; 3.1 percent organic matter; and 15, 12, 120, 1308, 308, 187, 340, 12, and 136 p/m, respectively, of NO_3, P (weak bray), K, Ca, Mg, SO_4, Fe, Al, Zn, and Mn. 8/ This spoil was typical of those found in the southern Appalachians with a low P level and high levels of SO_4, Fe, and Al. It was atypical in that the pH was moderately high and there was a high level of Ca.

The survival of loblolly pine seedlings was significantly affected (P=0.10) by an infection with *P. tinctorius* and by fertilization (Table 1). Two years after outplanting, seedlings infected with *P. tinctorius*, independent of fertilizer treatment, had 32 percent greater survival than control seedlings. Conversely, fertilization reduced survival irrespective of ectomycorrhizal treatment by 45 percent. The interaction of the two treatments resulted in some moderation of their opposite effects, but there was a persistent increase in survival associated with an infection by *P. tinctorius*. Fertilized seedlings with *P. tinctorius* had 74 percent greater survival than fertilized control seedlings and unfertilized seedlings with *P. tinctorius* had 15 percent greater survival than seedlings without *P. tinctorius* or fertilizer.

Table 1. Survival, growth, and relative growth of loblolly pine with or without *P. tinctorius* and with or without fertilizer after two years on a coal spoil in Tennessee.

Treatment	Percent Survival	Height	Root Collar Diameter	PVI
		Growth		
		cm	mm	cm^3
P. tinctorius	75	18.4	2.9	448.6
Control	57	14.6	2.1	219.6
Fertilized	47	23.0	3.7	390.8
Unfertilized	85	13.3	1.9	277.4
P. tinctorius Fertilized	59	24.6	4.1	603.4
P. tinctorius Unfertilized	91	14.4	2.0	293.8
Control Fertilized	34	20.2	3.1	178.2
Control Unfertilized	79	12.2	1.7	260.9
		Relative Growth		
P. tinctorius		1.1	0.7	5.0
Control		0.9	0.5	2.1
Fertilized		1.6	0.8	3.6
Unfertilized		0.8	0.5	3.5
P. tinctorius Fertilized		1.4	0.9	5.7
P. tinctorius Unfertilized		1.0	0.5	4.3
Control Fertilized		1.3	0.7	1.6
Control Unfertilized		0.7	0.4	2.7

8/ Chemical analyses were done by A&L Agricultural Laboratories, Inc., 2176 Dunn Avenue, Memphis, Tennessee 38114

Seedling growth was also significantly affected (P=0.10) after 2 years by an infection with *P. tinctorius* and by fertilization (Table 1). Unlike survival, both treatments resulted in increased growth. Independent of fertilizer treatment, the relative height growth of seedlings infected with *P. tinctorius* was 22 percent greater and the relative root collar diameter growth 40 percent greater than that of the control seedlings. These growth differences became more apparent when combined with survival in the relative plot volume index. The RPVI of seedlings with *P. tinctorius* was 138 percent greater than that of the seedlings without *P. tinctorius*. Greater differences in growth resulted from fertilization. Fertilized seedlings, independent of ectomycorrhizal treatment, had a relative height and root collar diameter growth 100 and 60 percent greater, respectively, than that of the unfertilized seedlings, but the RPVI was only 3 percent greater, reflecting the low survival associated with fertilization. The interaction of the two treatments produced similar results. The relative height growth of the fertilized seedlings with *P. tinctorius* was 8 percent greater and the relative root collar diameter growth 29 percent greater than that of the fertilized seedlings without *P. tinctorius*. The subsequent 256 percent difference in RPVI reflected the increased growth and survival due to *P. tinctorius*, but the difference was accentuated by the extremely poor survival of the fertilized control seedlings. Alternately, the relative growth in height, root collar diameter, and PVI of unfertilized seedlings with *P. tinctorius* was 43, 25, and 59 percent greater, respectively, than that of the seedlings without *P. tinctorius* or fertilizer.

DISCUSSION

It can be concluded that *P. tinctorius* ectomycorrhizae significantly improved the survival and growth of loblolly pine seedlings on coal spoils. This ecologically adapted fungal symbiont provides the host a greater physiological tolerance of the adverse conditions prevalent on these sites. It is believed that the increased capacity for the absorption of moisture and nutrients afforded by *P. tinctorius* was of particular importance in this study due to competition with the grasses planted on the spoil. The establishment of a grass cover, required by most state reclamation laws, provided a degree of realism in that it presented a competition variable often ignored in reclamation studies. The results of this study indicate that the seedlings infected with *P. tinctorius* were superior in their ability to survive and grow under these conditions.

Fertilization was found to be both a positive and a negative factor in the establishment of pine on this site. Seedling growth was enhanced by this treatment but survival was substantially reduced. Several possible explanations exist for the relatively poor survival of fertilized seedlings. The application of fertilizer to the spoil surface stimulated grass growth, resulting in increased competition for moisture and nutrients. In some instances, the grass overtopped the seedlings. It is also probable that fertilization during the first growing season stimulated excessive top growth, which the root system was physiologically incapable of supporting. The problem of an undesirably high top/root ratio would be accentuated by the competition factor. It is apparent that further research is warranted with respect to the rate and timing of fertilizer applications to coal spoils when both ground cover and seedling establishment are desired.

A consideration of the interaction of the two treatments indicates that either of the treatment combinations with *P. tinctorius* ectomycorrhizae were superior to those with control seedlings. Unfertilized seedlings with *P. tinctorius* was the combination of treatments producing results most closely approximating commonly accepted reclamation objectives, i.e. maximization of site protection and productivity. Although the fertilized seedlings with *P. tinctorius* exhibited greater initial growth, the fertilizer-induced lower survival of this combination renders it less desirable. It is probable that an adjustment in the timing and rate of fertilizer applications would enable the seedlings to derive maximum benefit from both *P. tinctorius* ectomycorrhizae and fertilization. Research is needed to further delimit the fertilizer variable such that the enhanced survival and growth afforded pine seedlings on coal spoils by an infection with *P. tinctorius* is not compromised to the detriment of overall establishment success.

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LITERATURE CITED

Bengtson, G. W., S. E. Allen, D. A. Mays, and T. G. Zarger.
1973. Use of fertilizers to speed pine establishment on reclaimed coal-mine spoil in northeastern Alabama: I. Greenhouse experiments. IN Hutnik, R. J., and G. Davis (eds.), Ecology and Reclamation of Devastated Land. Vol. 2, pp. 199-225. Gordon and Breach. New York. 504 pp.

Berry, C. R.
1979. Slit application of fertilizer tablets and sewage sludge improve initial growth of loblolly pine seedlings in the Tennessee Copper Basin. Reclam. Rev. 2:33-38.

Berry, C. R., and D. H. Marx.
1978. Effects of *Pisolithus tinctorius* ectomycorrhizae on growth of loblolly and Virginia pines in the Tennessee Copper Basin. U.S. For. Serv. Res. Note SE-264. 6 pp.

ile, N., and J. F. Hennen.
1969. In vitro culture of *Pisolithus tinctorius* mycelium. Mycologia 61: 195-198.

ampky, J. R., and J. E. Peterson.
1963. *Pisolithus tinctorius* associated with pines in Missouri. Mycologia 55:675-678.

arks, G. C., and T. T. Kozlowski.
1973. Ectomycorrhizae - Their Ecology and Physiology. Academic Press, New York. 444 pp.

arx, D. H.
1969. The influence of ectotrophic mycorrhizal fungi on the resistance of pine roots to pathogenic infections. I. Antagonism of mycorrhizal fungi to root pathogenic fungi and soil bacteria. Phytopathology 59:153-163.

arx, D. H.
1975. Mycorrhizae and establishment of trees on strip-mined land. Ohio J. Sci. 75:288-297.

arx, D. H., and J. D. Artman.
1979. *Pisolithus tinctorius* ectomycorrhizae improve survival and growth of pine seedlings on acid coal spoils in Kentucky and Virginia. Reclam. Rev. 2:23-31.

arx, D. H., and W. C. Bryan.
1975. Growth and ectomycorrhizal development of loblolly pine seedlings in fumigated soil infested with the fungal symbiont *Pisolithus tinctorius*. For. Sci. 22:245-254.

arx, D. H., W. C. Bryan, and C. E. Cordell.
1976. Growth and ectomycorrhizal development of pine seedlings in nursery soils infested with the fungal symbiont *Pisolithus tinctorius*. For. Sci. 22:91-100.

Marx, D. H., W. C. Bryan, and C. E. Cordell.
1977. Survival and growth of pine seedlings with *Pisolithus* ectomycorrhizae after two years on reforestation sites in North Carolina and Florida. For. Sci. 23:363-373.

Medve, R. J., F. M. Hoffman, and T. W. Gaither.
1977. The effect of mycorrhizal-forming amendments on the revegetation of bituminous strip-mine spoils. Bull. Torrey Bot. Club 104:218-225.

Plass, W. T., and W. G. Vogel.
1973. Chemical properties and particle-size distribution of 39 surface-mine spoils in southern West Virginia. U.S. For. Serv. Res. Pap. NE-276. 8 pp.

Schramm, J. R.
1966. Plant colonization studies on black wastes from anthracite mining in Pennsylvania. Trans. Am. Philos. Soc. 56:1-194.

Vogel, W. G.
1975. Requirements and use of fertilizers, lime, and mulch for vegetating acid mine spoils. IN NCA/BCR (ed.), Third Symposium on Surface Mining and Reclamation. Vol. 2, pp. 175-188. National Coal Association, Washington, D. C. 355 pp.

Zarger, T. G., G. W. Bengtson, J. C. Allen, and D. A. Mays.
1973. Use of fertilizers to speed pine establishment on reclaimed coal-mine spoil in northeastern Alabama. II. Field Experiments. IN Hutnik, R. J., and G. Davis (eds.), Ecology and Reclamation of Devastated Land. Vol. 2, pp. 227-236. Gordon and Breach, New York. 504 pp.

DEVELOPING FUSIFORM RUST-RESISTANT SEED ORCHARDS USING SURVIVORS OF ARTIFICIAL INOCULATION TESTS[1]

H.R. Powers, Jr.[2]

Abstract.--The healthy survivors of artificial inoculation tests were planted in fusiform rust-resistant seed orchards. After 3 years of exposure to natural infection in field plantings, trees in the most resistant families had less than 10% infection. Using survivors extends the genetic base of rust-resistant material currently available and also increases the level of resistance in rust-resistant orchards.

INTRODUCTION

Fusiform rust, caused by Cronartium quercuum (Berk.) Miyabe ex Shirai f. sp. fusiforme, is the most serious disease of loblolly (Pinus taeda L.) and slash (P. elliottii var. elliottii Engelm.) pine in the southern United States (Phelps 1973, Powers et al. 1975). Recent estimates of damage caused by this disease exceed $110 million annually due to both mortality and quality loss of forest products. In many areas of the South, management practices such as intensity of site preparation, choice of species for planting, planting density, and type of product to be produced, are determined by the severity of this disease. In the past, effective controls have been limited to the use of fungicidal sprays in forest tree nurseries, pruning infected limbs, and excising stem cankers on high-value ornamental and seed orchard trees. Effective control in the forest, however, depends upon the development of disease-resistant strains of pine (Powers et al. 1979).

Most forest industries and state forestry organizations in the area of the South most seriously affected by this disease are developing seed orchards for the production of rust-resistan seedlings. Genetic resistance in both slash and loblolly pine has been demonstrated (Jewell 1964, Zobel et al. 1971), and superior trees with resistance have been selected. The rust-resistan orchards were developed by the standard practice of making grafts from the selected rust-resistant trees. Unfortunately, the number of proven rust-resistant clones is relatively low, particularly in loblolly pine. Therefore, the genetic base of these orchards needs to be expanded by any means possible.

Progeny of most resistant clones have alread been tested for rust resistance by artificial inoculation in greenhouse tests. The first greenhouse tests were made in 1971, and it was felt at that time that the healthy survivors of these inoculations were promising genetic material for future use in rust resistance work. Our objectiv was to determine the most effective use of inoculation test survivors in an overall program for the development and breeding of rust-resistant pines.

MATERIALS AND METHODS

The seedlings were inoculated by using the concentrated basidiospore spray (CBS) inoculation system (Matthews and Rowan 1972). This procedure allowed for the standardized evaluation of large numbers of pine seedlings under controlled conditions. Evaluations were completed in 6 to 9 months, and the healthy survivors were transferre to containers and grown in the greenhouse for several months prior to establishment in the fiel The standard field planting design was a randomi block, with eight replications. Each replication contained a 10-tree row, planted in random order, of each family included in the study.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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During the next few years clones with higher levels of resistance, as well as the progeny from some of the first controlled pollinations between resistant parents, became available for testing. With this improved material available, it was decided in 1974 to establish a seed orchard for the production of rust-resistant seedlings. Half of this new orchard was established as a standard clonal orchard, with the remainder designed as a seedling seed orchard using the survivors of the most resistant families from the artificial inoculation tests. The rust-resistant seed orchard of 60 acres is one of the largest in the southern United States, and the first to include seedling orchard blocks developed by use of inoculation tests survivors.

Each seedling seed orchard block contained 50 replications. Each replication included a single tree, placed at random, of each family included in the block. Usually 12 to 16 half- or full-sib families were used in each block. The basic principal of the seedling seed orchard is to space the trees very close together, in our case 5 x 15 feet. In order to reach an eventual spacing of approximately 30 x 30 feet, over 90 percent of the original seedlings must be removed. This means about 5 seedlings of the original 50 of each family will remain as crop trees. The first removals are those trees that become diseased by natural infection after they were planted in the field. Subsequent removals were based on growth and form characteristics, and on family history regarding rust resistance. Data were taken on rust infection, height, and growth characteristics the third year after planting and every year thereafter.

RESULTS

Progeny Test Blocks

The earliest results obtained using the survivors of artificial inoculation tests came from progeny test blocks. After 6 growing seasons in the field, the incidence of fusiform rust on these survivors ranged from 0 to 49% (Table 1). The controls, which were commercially available seedlings from a state nursery, had 74% infection. The height of various half-sib families in the test ranged from 11.3 feet for a loblolly x shortleaf hybrid to 16.8 feet for family 11-16 (Table 1).

Scions were collected from the best individuals among the 80 members of each family in this progeny test to make grafts for clonal seed orchards. Most of these new selections were from families with the least incidence of rust, although outstanding individuals in families with higher levels of rust infection were included to expand the genetic base of available material. Even the individuals from families with somewhat lower levels of rust resistance had survived both severe greenhouse inoculations and 6 years of natural infection in the field. In addition, some of them were among the tallest trees in the test. However, there was no direct correlation between average height and overall incidence of rust among the survivors in this test. Family 11-16 had the tallest average height in the test and was intermediate in rust incidence (21% infection), ranking 8th out of 12 families in the test.

Seedling Seed Orchard Blocks

The first seedling seed orchard blocks were planted in 1975. These blocks included inoculation test survivors from 16 half- and full-sib families rated intermediate to good for rust-resistance following greenhouse tests. After 3 years exposure to natural field infection, the families ranged from 2 to 47% infection (Table 2). No susceptible checks were included in the orchard blocks. There was a good correlation between the results from the artificial inoculation tests and subsequent natural infection on the survivors in the field. For example, the first 10 families listed in Table 2 were consistently among the most resistant in artificial inoculations, and survivors of these families all had 10% or less infection after 3 years exposure in the field. The next 5 families were intermediate in greenhouse test and ranged from 16 to 36% infected in the field. Family 10-31, the most heavily infected in the field at 47%, was a marginal candidate for inclusion in this planting since in two artificial inoculation tests it had only 25% less infection than the susceptible checks.

Height measurements were taken after 4 years. Averages for the tallest 10 trees of each family were used since this would be the group from which selections probably would be made for eventual crop trees. These averages for each family ranged from 7.4 feet for a shortleaf hybrid to 13.9 feet for two selections from Florida (Table 2). After 4 growing seasons, at least 20 individuals remained from the original 50 in the case of 15 out of 16 families included in the block. These trees represent the most resistant portion of each family, and will provide an adequate number for selection of final crop trees in this orchard block.

DISCUSSION

When survivors of artificial inoculation tests are planted in the field, in either progeny test blocks or in seedlings seed orchard blocks, they are again subjected to a vigorous screening for rust resistance. Individuals that have survived a heavy artificial inoculation in the juvenile stage as seedlings, and up to 6 years of exposure to natural infection in the field, should

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be some of the most resistant material currently available.

Most progenies tested for rust resistance by artificial inoculations were open-pollinated seed obtained from seed orchard trees, or from trees in clone banks were superior selections were grouped together for evaluation prior to being included in rust-resistant seed orchards. It is likely that the pollen parents of the seedlings being tested are also improved genetic material, since they also were located in the orchards or clone banks. In addition, most seedlings in inoculation tests were members of half-sib families, with many pollen parents involved in the crosses. Therefore, these seedlings represent a broader genetic base than the grafts in clonal orchards, since they were derived from a large number of parents. The parents involved in these crosses included most of the rust-resistant selections available at this time, as well as other trees in the orchards that have other favorable characteristics.

The most obvious immediate use of the best individuals among the survivors in these plantings would be as new selections to provide scion material for grafting and inclusion in new clonal orchards. In addition, as the individuals in the progeny test blocks and the seedling seed orchard mature and begin to produce seed, their progeny can again be screened for resistance and the cycle repeated with a new generation of survivors.

The material established in both the clonal and seedling seed orchard blocks are already producing a few cones. A sufficient number of cones should be available within 4 to 5 years for the production of approximately one-half million rust-resistant seedlings. Since both clonal and seedling seed orchard blocks were used to establish the rust-resistant orchard, it will then be possible to determine which type of orchard produces seed with the highest levels of rust resistance.

Eventual production from the 60-acre seed orchard should reach approximately 6 million seedlings annually for use in high rust-hazard areas. It is hoped that the first generation seed orchard blocks will produce seedlings that will reduce the average incidence of rust in slash pine by 50% and in loblolly pine by 40%. Successive generations of seedling seed orchard blocks, including the most resistant of the survivors from the first generation orchards, should eventually reduce the overall incidence of rust to approximately 25% of that in currently available commercial seedlings.

Table 1.--Fusiform rust infection (after 6 years) and average height of 13 loblolly families in "survivor" progeny test block 301.

Family	Rust infection	Average height
	Percent	Feet
SML-9	0	13.3
Hit Hy	3	11.3
10-6	7	13.4
11-9	10	14.6
LP	15	15.0
11-20	18	13.5
10-5	18	14.8
11-16	21	16.8
L29R	26	12.8
1582-11	29	13.7
4625-3	30	14.6
1590-6	49	14.8
Check	74	14.1

able 2.--Fusiform rust infection (after 3 years) and height growth (after 4 years) of 16 loblolly families in the rust-resistance seedling seed orchard block 151.

Family	Rust Infection	Average height of tallest 10 trees
	Percent	Feet
9-Rx1495-35	2	12.7
ML-9	2	11.4
1-9	6	11.8
DR	6	13.0
FS	6	13.5
2R	7	12.9
.H.	7	7.4
1-20	7	11.5
495-35	9	11.3
0-5	10	13.6
5-42	16	13.2
318	19	13.1
-605	21	13.9
-601	25	13.9
9R	36	11.4
0-31	47	12.5

LITERATURE CITED

Jewell, F. F., and S. L. Mallett.
1964. Resistance to fusiform rust in slash pine as shown by artificial inoculation. Phytopathology 54:1294.

Matthews, F. R., and S. J. Rowan.
1972. An improved method for large-scale inoculations of pine and oak with Cronartium fusiforme. Plant Dis. Rep. 56:931-934.

Phelps, W. R.
1973. Fusiform rust incidence survey for 1971-1973. U.S. Dep. Agric., For. Serv., Southeast. Area State and Priv. For. 69 p.

Powers, Jr., H. R., J. F. Kraus, and H. J. Duncan.
1979. A seed orchard for rust resistant pines-progress and promise. Ga. For. Res. Counc., Ga. For. Res. Pap. 1. 8 p.

Powers, Jr., H. R., J. P. McClure, H. A. Knight, and G. F. Dutrow. 1975. Fusiform rust: forest survey incidence data and financial impact in the South. U.S. Dep. Agric., For. Serv. Res. Pap. SE-127. 16 p.

Zobel, B., R. Blair, and M. Zoerb.
1971. Using research data: disease resistance. J. For. 69:386-389.

LATENT FUSIFORM RUST INFECTIONS IN SLASH AND LOBLOLLY PINE NURSERY STOCK[1]

S. J. Rowan[2] and David Muse[3]

Abstract.--Significant numbers of slash and loblolly pine seedlings with fusiform rust infections do not display symptoms before they are lifted from nursery beds. Latent infected seedlings are planted in new plantations at rates that are related to infection levels observed at time of lifting from nursery seedbeds. Since galls develop more slowly in loblolly than in slash pine, the problem is greater with this species.

Fusiform rust, caused by Cronartium quercuum (Berk.) Miyabe ex Shirai f. sp. fusiforme (Cumm.) Burdsall & Snow, is the most serious disease of planted slash (Pinus elliottii Engelm.) and loblolly pines (P. taeda L.), and its incidence in new plantings is increasing (Schmidt et al., 1974). Despite fungicidal spraying to minimize infection in nurseries, an average of 2.5 percent of the slash and loblolly pines produced each year in southern nurseries have visible rust galls in December (Rowan, 1977). Czabator (1971) recognized that some proportion of the seedlings examined at lifting may have undetectable, latent infections. Since these seedlings are very likely to die after they are outplanted, it would be useful to know how common the phenomenon of latent infection is.

In this paper we report an exploratory study in which the rate of gall development was monitored monthly in both greenhouse and nursery grown slash and loblolly pine seedlings.

METHODS

Seedlings of both slash and loblolly pines were artificially inoculated with the fusiform rust fungus in May, and 31 replicates of each species were retained in greenhouse culture and 42 replicates of each species were placed on a nursery seedbed. The inoculation was equivalent to heavy natural exposure. A replicate consisted of 25 seedlings in a 6-inch plastic pot. The pots were arranged in both the greenhouse and nursery in a randomized complete block design with three blocks. Natural rust infections were minimized by selecting a nursery with a low rust hazard rating (Georgia Forestry Commissions' Hightower Nursery) and by spraying all seedlings placed within the nursery 3 times each week from May through July 7 with ferbam formulated with a spreader sticker and applied at the rate of 3 pounds per acre in 75 gallons water.

Starting in July, seedlings were examined monthly, and the percentage of seedlings with galls was recorded. To determine the percentage of seedlings with latent infections in any month, the infection percentage for that month was compared with that at 16 months after inoculation. To determine if significant numbers of natural infections were established in nursery grown seedlings and to minimize the possibility that additional latent infections existed in seedlings 16 months after inoculation, 3 replicates were returned to the greenhouse at monthly intervals beginning 3 months after inoculation and these we compared to the greenhouse grown seedlings. As s as definite galls were present on seedlings, they were removed from the pot by cutting at groundlin This provided additional room in the pots for gro of the remaining seedlings. Final readings were made 16 months after inoculation of both the gree house and nursery grown seedlings.

The data were somewhat characteristic of growth curve data and were analyzed using the following indexed growth model:

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$$Y_{ij} = \alpha_i + \beta e^{-\gamma(T_{ij} - K)} + \varepsilon_{ij}$$

Where Y_{ij} denotes the percentage of galled seedlings observed for the i^{th} block (replicate) at the j^{th} point in time, α_i is the maximum percentage of galled seedlings expected for the i^{th} block, β is the degree of slope, $e = 2.7183$, γ is weighted factor for the exponential term, K is a correction factor, T_{ij} denotes time after inoculation in months, and ε_{ij} denotes the error term for the i^{th} block and j^{th} point in time.

RESULTS AND DISCUSSION

Although all seedlings in this study were inoculated on the same day with equal numbers of basidiospores of the fusiform rust fungus, the rate of gall development was markedly affected by the environment in which the infected seedlings were grown during the 16 months after inoculation (Table 1). On seedlings grown in the greenhouse, symptoms of gall development first appeared 2 months after inoculation. Easily detectable galls were first observed in greenhouse grown seedlings 3 months after inoculation, but nursery grown seedlings failed to show these symptoms until 6 months after inoculation (equivalent to observations in November). Thus, rust infections may not be apparent in nursery seedbeds until November.

Using the data obtained in this study and the above nonlinear growth curve model, a least squares analyses of the data produced the following results:

1. Nursery grown slash:

   $\hat{\alpha} = Y + 3.522\ e^{-.37(T - 11)}$

   where $\hat{\alpha}_1 = 82.2$, $\hat{\alpha}_2 = 88.6$, $\hat{\alpha}_3 = 84.4$,

   $6 \leq T_{ij} \leq 16$;

2. Nursery grown loblolly:

   $\hat{\alpha} = Y + 10.038\ e^{-.24(T - 11)}$

   where $\hat{\alpha}_1 = 79.3$, $\hat{\alpha}_2 = 83.6$, $\hat{\alpha}_3 = 77.5$,

   $6 \leq T_{ij} \leq 16$;

3. Greenhouse grown slash:

   $\hat{\alpha} = Y + 5.515\ e^{-.18(T - 7)}$

   where $\hat{\alpha}_1 = 89.2$, $\hat{\alpha}_2 = 81.8$, $\hat{\alpha}_3 = 87.7$,

   $3 \leq T_{ij} \leq 12$;

4. Greenhouse grown loblolly:

   $\hat{\alpha} = Y + 2.731\ e^{-.35(T - 7)}$

   where $\hat{\alpha}_1 = 74.7$, $\hat{\alpha}_2 = 79.6$, $\hat{\alpha}_3 = 75.2$,

   $3 \leq T_{ij} \leq 12$.

In these equations, $\hat{\alpha}$ is the final infection percentage, and Y is the infection percentage T months after inoculation.

Although these equations fit the observed data rather well, their value for prediction is unproven. The equations were generated from data on seedlings whose final infection rates were 84 percent for slash pine and 76 percent for loblolly pine. At the much lower infection rates in protected nurseries, completely different relationships may exist. Table 1 and the equations, however, indicate that large numbers of seedlings that will eventually develop galls appear healthy in November and December, when southern nurseries typically begin lifting and shipping seedlings.

Table 1.--Percentages of fusiform rust galled seedlings observed in slash and loblolly pine when grown in greenhouse or nursery seedbeds by both month after seedlings were artificially inoculated and calendar month.

Months after inoculation	Month	Galled seedlings Nursery grown Slash	Galled seedlings Nursery grown Loblolly	Galled seedlings Greenhouse grown Slash	Galled seedlings Greenhouse grown Loblolly
		------------Percent------------			
2	July	0.0	0.0	0.5	0.3
3	Aug.	0.0	0.0	74.9	65.7
4	Sept.	0.8	0.2	76.6	68.0
5	Oct.	1.7	4.5	78.3	71.0
6	Nov.	62.6	46.4	80.0	73.3
7	Dec.	70.6	55.9	80.9	74.1
8	Jan.	73.9	59.0	81.7	74.5
9	Feb.	75.6	60.9	82.1	74.9
10	March	80.7	65.7	82.5	74.9
11	April	82.5	72.6	83.8	76.0
12	May	83.5	74.5	84.2	76.4
13	June	83.7	74.7	84.2	76.4
14	July	83.9	74.9	84.2	76.4
15	Aug.	83.9	75.7	84.2	76.4
16	Sept.	84.0	76.0	84.2	76.4

Since galls developed more slowly on loblolly than on slash pine, the number of latent infections was larger on loblolly pine. The equation indicates that loblolly pines have 10.7 percent more latent infections than slash pine in December.

In view of the high investment in seedlings after they leave the nursery, additional study of the rate of gall development seems justified. We are planning a study in which the equations presented here will be tested on seedlings with a wide range of infection percentages. This study should provide a means of predicting the final fusiform rust infection percentages in slash and loblolly pine stocking from observations made at the time seedlings are lifted from the nursery seedbed.

LITERATURE CITED

Czabator, F. J.
1971. Fusiform rust of southern pines - a critical review. USDA Forest Service Research Paper SO-65. 39 p.

Rowan, S. J.
1977. Incidence of fusiform rust in Georgia forest tree nurseries, 1959-1973. Tree Planters' Notes 28(2):17-18, 29.

Schmidt, R. A., R. E. Goddard, and C. A. Hollis.
1974. Incidence and distribution of fusiform rust in slash pine plantations in Florida and Georgia. Instit. Food and Agric. Sci., Univ. of Fla. Bull. 763. 21 pp.

IMBIBITION TEMPERATURES AFFECT SEED MOISTURE UPTAKE, GERMINATION, AND SEEDLING DEVELOPMENT[1]

James P. Barnett[2]

Abstract.--Temperatures of seed and water during imbibition of southern pine seeds can affect seed germination and seedling development. Temperatures also affect rate of moisture uptake and when germination begins. Imbibition temperatures had little effect on longleaf and slash pine germination and seedling development. But loblolly pine was affected by absorption temperatures, and the effects varied greatly by single-tree lots.

INTRODUCTION

Temperatures at which seeds absorb water have an important effect on germination and early seedling growth of several agronomic species (Pollock and Toole 1966, Hobbs and Obendorf 1972). Imbibition temperatures lower than 75° F often harm these species. In lima beans an important part of this temperature sensitivity is related to initial seed moisture (Pollock 1969); when seed moisture was below 13 percent at the time absorption started, survival and seedling vigor decreased. But this relationship probably does not exist in pine seeds; they typically require drying to moisture contents lower than 13 percent so that storability will be maintained. We know little about how absorption temperatures affect pine seed germination and seedling growth. But light exposures during stratification, and presumably in the absorption phase, do increase speed of germination of loblolly pine (*Pinus taeda* L.) seeds (McLemore 1964).

The conditions under which water absorption takes place in pine seeds are usually ignored, but current stratification techniques make control of these conditions easy (Hosner et al. 1959, Barnett 1971). I have begun a series of tests to evaluate how imbibition temperature and light regimes affect germination and early seedling development of southern pines. Early tests showed that temperatures during moisture uptake significantly affect loblolly germination and seedling development, and the response varies greatly with individual seed lots[3]. Because of these positive results, I did more testing of temperatures of seed and water during imbibition.

METHODS

I used three composite local seed lots each of loblolly, slash (*P. elliottii* Engelm.), and longleaf (*P. palustris* Mill.). And I used several half-sib lots of loblolly seed in supplemental tests. The initial seed moisture contents ranged from 6 to 10 percent. Empty seeds were removed by flotation (Barnett and McLemore 1970). The 20 treatments were combinations of five absorption temperatures (48°, 60°, 72°, 84°, and 96° F), two light levels during absorption, and two during germination. Light levels during absorption and germination were total darkness and 1300 lux from cool-white fluorescent bulbs. Darkness was maintained in lightproof cloth bags. Light was continuous during absorption, but during germination I used a 16-hour photoperiod. I soaked seeds in germination dishes by placing them at the desired temperature and then moistening the Kimpak germination medium with water at the same temperature.

During imbibition, I measured rate of moisture uptake by providing extra seeds from each of three replications for sampling of moisture content. These tests were run for 96 hours. Moisture content was expressed on a dry-weight basis after seeds dried at 180° F for 24 hours.

All germination tests were conducted at 72° F after seeds had been soaking for 48 hours at the prescribed temperatures. Duplicate 100-seed samples were tested for each replication for 28 days. As germination began and radicles extended about 1/2 inch, 40 seedlings from selected treatments were transplanted into styroblock containers filled with a peat-vermiculite medium. When seedlings were 12 weeks old, I measured total dry weight, then analyzed statistical differences at the 0.05 level in a completely randomized design.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

[2] Principal Silviculturist, Southern Forest Experiment Station, Forest Service--USDA, Pineville, Louisiana 71360.

[3] Unpublished data, Southern Forest Experiment Station, Pineville, Louisiana 71360.

RESULTS

Moisture Uptake

Water absorption was closely related to temperature during the early periods of moisture uptake, but the absorption pattern was different for each species (table 1). Loblolly seeds absorved moisture faster at the higher temperatures during the first 24 hours of uptake. After 48 hours not much more absorption took place and maximum moisture contents reached 35 percent. This is the highest that moisture contents of loblolly seeds will get before seedcoats rupture and germination begins (Barnett 1976).

The rate of moisture uptake was greater in slash pine seeds than in loblolly, and it leveled off only after longer exposures to high temperatures. Higher temperatures again speeded absorption. At 48°, 96 hours were needed for the seed to reach 40 percent moisture content. But at 84° or 96° this same moisture level was reached in 24 hours (table 1). Seedcoat rupture and germination of slash seeds began at a moisture content of about 40 percent. After the longer periods of exposure to the higher temperatures, rate of absorption declined. Apparently absorption did not continue because temperatures were too high for seedling development.

Longleaf seeds absorbed moisture at about the same rate as slash seeds, but absorption went on longer. At a moisture content of about 55 percent, seedcoat rupture and germination began; moisture levels of seeds imbibed at 72° reached 75 percent after 96 hours. But the absorption rate of seeds imbibed at higher temperatures declined, again probably because seedling development is not normal at such temperatures. Other studies have shown that high temperatures adversely affect development of germinating seeds (Barnett 1979).

The absorption data support earlier results suggesting that seedcoats restrict the quantity of uptake by limiting how much the megagametophyte and embryo can expand (Barnett 1976). Of course the less dormant seeds are least restrained by the seedcoats. Loblolly seeds are most dormant, then slash, then longleaf.

Germination

Temperature and light conditions during 48 hours of absorption had statistically significant, but relatively unimportant, effects on germination (table 2). Imbibition at 96° did lower germination in all three species. Only in loblolly pine was there any difference due to light condition; at 72° germination in the dark was lower than at all other combinations of light and temperature.

The treatment effects on germination values, which reflect speed and completeness of germination (Czabator 1962), followed the same trends established for germination percentages. Absorption at 96° reduced germination values for all species (table 2). Seeds of slash and longleaf pine soaked at 48° had lower values than those soaked at 72°, so the germination rate was slower. Loblolly germination values were affected by both light and temperature regimes. Seeds soaked at 60° in light had greater germination values than all other treatments, but the differences were too small to be of practical importance.

Because absorption conditions affected germination of loblolly seed more than they affected the other species, I did supplemental tests with single-tree lots of loblolly seeds. Light conditions during imbibition markedly affected germination when tests were made in the dark (fig. 1). Germination in the dark was higher when seeds had soaked under light. It also increased as absorption temperatures increased.

Germination in light was unaffected by the light level during absorption. But temperature of moisture uptake did affect germination, and the response varied greatly by seed lot (fig. 1). In lot 1, high temperatures resulted in lower germination. Seeds of lot 2 germinated better when soaked in light at 96°. Lot 3 seeds were least affected by conditions of moisture uptake.

Seedling Development

Light levels during absorption did not affect seedling development, but temperatures did (fig. No differences in seedling weights due to temperature of water absorption were detectable in longleaf and slash pines, probably because of the wid variation within treatments. Loblolly seedlings were affected by absorption temperature--dry weig were greater for 84° than for 48°. Supplementary tests with single-tree lots of loblolly pine agai showed a wide variation in dry weights among seed lots. No effect of soaking temperature on seedling development occurred consistently.

CONCLUSIONS

Recognition of the physical nature of water uptake has long been accompanied by the assumptio that little of biological interest happens during this relatively short period. So, many studies o pine seed germination start with soaked or partly imbibed seeds, and little information is provide on the conditions under which this moisture is absorbed. Results of this study show, however, that the temperature at which water absorption occurs can affect seed germination and seedling development. Response varies greatly by single-tree lots. More research is needed so we can critically evaluate the process involved, particularly in loblolly pine where the effects are the greatest.

Table 1.--Average moisture contents of loblolly, slash, and longleaf pine seeds[1]

Species	Hours of absorption	Absorption temperature (°F)				
		48	60	72	84	96
		Percent				
Loblolly	8	24	27	27	27	29
	24	29	30	31	32	33
	48	32	32	33	35	33
	72	32	34	34	35	33
	96	33	34	35	35	34
Slash	8	24	27	30	32	33
	24	32	35	38	41	44
	48	39	39	42	47	47
	72	38	40	46	49	47
	96	41	44	48	49	48
Longleaf	8	24	26	28	30	39
	24	32	37	42	48	40
	48	39	50	59	59	44
	72	45	57	66	63	41
	96	52	68	75	68	57

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[1] Staggered lines show moisture contents where seedcoats are ruptured and germination begins. Normally this occurs at about 36 percent for loblolly (Barnett 1976), 40 percent for slash, and 55 percent for longleaf pine.

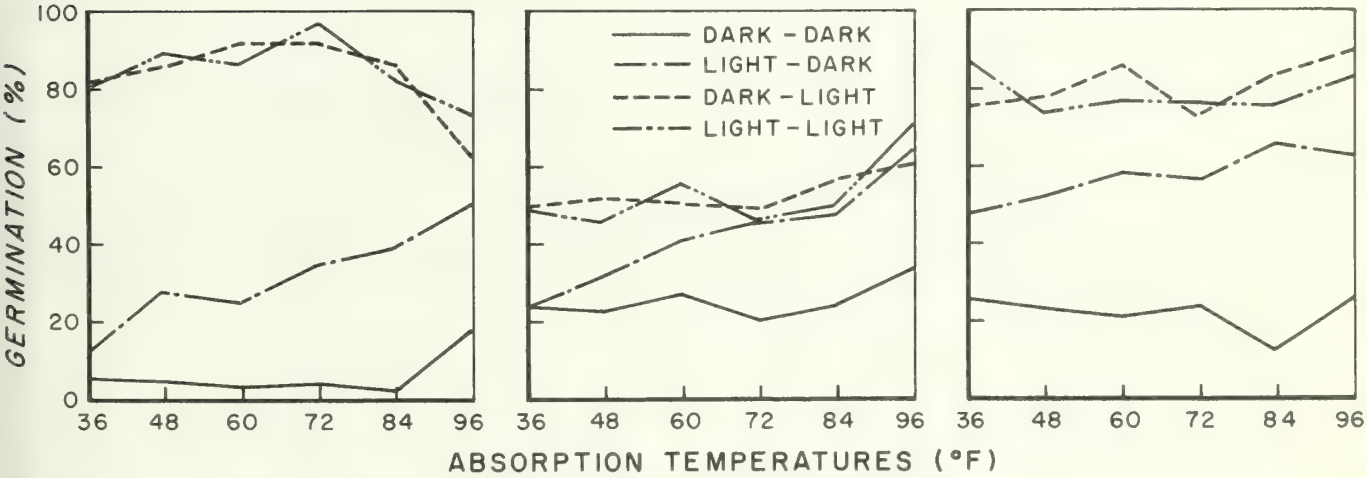

Figure 1.--Germination of single-tree lots of loblolly pine seeds as affected by absorption temperatures and light conditions during absorption and germination.

Table 2.--Germination percentages and values of loblolly, slash, and longleaf pine seeds after varying absorption temperature and light regimes for 48 hours 1/

Temperature	Light condition	Germination			Germination value		
		Loblolly	Slash	Longleaf	Loblolly	Slash	Longleaf
°F		Percent					
48	Light	92 a	79 a	82 a	17.2 c	23.6 b	25.1 b
	Dark	93 a	82	88	17.5 cd	23.3	30.2
60	Light	94 a	78 a	86 a	20.7 a	26.4 ab	32.8 a
	Dark	96 a	78	86	18.7 b	25.2	31.6
72	Light	94 a	80 a	87 a	18.0 bc	29.6 a	31.0 a
	Dark	86 c	78	87	14.5 f	26.7	34.4
84	Light	92 a	76 a	83 a	16.5 e	26.1 ab	27.4 ab
	Dark	94 a	80	86	17.9 bc	27.3	30.5
96	Light	91 b	70 b	76 b	16.4 de	20.8 c	20.3 c
	Dark	90 b	64	82	15.9 e	18.4	25.4

1/ Species means followed by the same letter are not significantly different at the 0.05 level. Slash and longleaf means were not significantly affected by light conditions, so average values for temperatures were analyzed for these species.

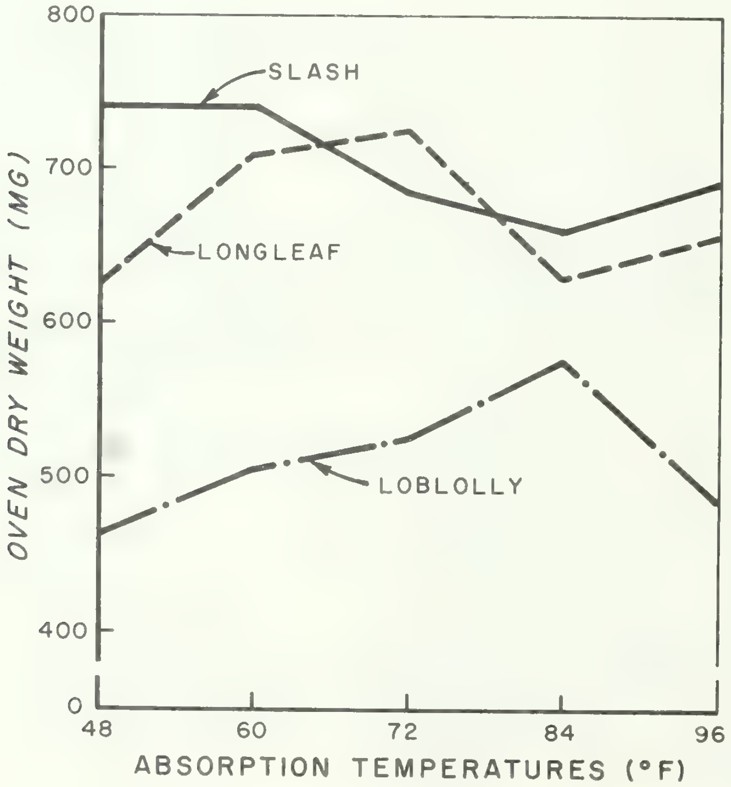

Figure 2.--Dry weights of longleaf, slash, and loblolly pine seedlings grown from seeds with different temperatures of moisture uptake and germinated and grown in light for 12 weeks.

LITERATURE CITED

rnett, James P.
1971. Aerated water soaks stimulate germination of southern pine seeds. U. S. Dep. Agric. For. Serv. Res. Pap. SO-67, 9 p. South. For. Exp. Stn., New Orleans, La.

rnett, James P.
1976. Delayed germination of southern pine seeds related to seedcoat constraint. Can. J. For. Res. 6:504-510.

rnett, James P.
1979. Germination temperatures for container culture of southern pines. South. J. Appl. For. 3(1):13-14.

rnett, James P., and B. F. McLemore.
1970. Storing southern pine seeds. J. For. 68:24-27.

abator, F. J.
1962. Germination value: an index combining both speed and completeness of pine seed germination. For. Sci. 8:386-396.

bbs, P. R., and R. L. Obendorf.
1972. Interaction of initial seed moisture and imbibitional temperature on germination and productivity of soybean. Crop Sci. 12:664-667.

sner, J. F., R. E. Dickerson, and L. Kahler.
1959. Storing loblolly pine seed in polyethylene bags as a substitute for stratification. J. For. 57:495-496.

Lemore, B. F.
1964. Light during stratification hastens dark-germination of loblolly pine seed. For. Sci. 10:348-349.

llock, B. M.
1969. Imbibition temperature sensitivity of lima bean seeds controlled by initial seed moisture. Plant Physiol. 44:907-911.

llock, B. M., and V. K. Toole.
1966. Imbibition period as the critical temperature sensitive stage in germination of lima bean seeds. Plant Physiol. 41:221-229.

GROWTH OF EASTERN WHITE PINE SEEDLINGS USING GREENHOUSE CULTURE TECHNIQUES [1]

Ronald L. Hay [2]

Abstract.--White pine seedlings were grown in Hillson-sized rootrainers in the greenhouse for seven months using supplemental light, carbon dioxide, and fertilizer treatments. Biomass and root collar diameter responded positively to extra photoperiod, but height growth was not influenced by light. Height growth was slowed by supplemental carbon dioxide and fertilizer. Root biomass was increased by supplemental carbon dioxide and light. Seedling top biomass was increased by fertlizer topdressings, but this treatment decreased root biomass.

INTRODUCTION

Eastern white pine (Pinus strobus L.) is one of the important native gymnosperms in Tennessee. It is common in the Blue Ridge Mountains of eastern Tennessee, and it is somewhat less abundant in the Cumberland Mountains. Its importance as a source of lumber has long been known locally, and markets have occasionally developed to increase the demand regionally. At one time, the largest eastern white pine in North America was growing in the mountains of East Tennessee.

More recently the demand for white pine lumber, Christmas trees, and ornamental landscaping products has greatly increased the demand for white pine planting stock. Each year for the last several years, the Tennessee Division of Forestry has not had an adequate supply of 2-0 white pine seedlings. Estimates have placed the potential demand far in excess of available seedlings, perhaps by as much as 500 percent. Demand for white pine planting stock has greatly exceeded available supplies in recent years, and there is every reason to believe that the trend will continue.

White pine has some seedling growth characteristics that lengthen its stay in the nursery, thereby increasing the difficulty and cost of high production efficiencies. For example, white pine seedlings do not usually develop secondary leaves during their first growing season. The cotyledons are functional until the epicotyl begins to elongate and the efficient, primary leaves appear. These leaves provide photosynthate during the first growing season. The overwintering buds appear relatively early, usually by mid-summer, and height growth stops. Seedlings are usually much too small to be considered for outplanting after one year in the nursery. During the second year in the nursery, secondary leaves are produced and most seedlings grow to sufficient size to survive outplanting.

Containerized culture of pines in greenhouses has numerous advantages over standard nursery culture techniques, especially for those species that have problems in nurseries. In a greenhouse, environmental problems can be readily controlled, while providing conditions conducive to seedling growth. The greenhouse environment facilitates the efficient use of fertilizers and inoculation of the growing medium with appropriate mycorrhizal symbionts, e.g., both supplemental slow-release fertilizers and fungal symbionts can be added to the growing medium before containers are filled. Subsequent applications of liquid fertilizers can be made during watering. Fertilizer can be formulated to meet specific needs at specific times to best stimulate growth. Timing of greenhouse operations is not dependent upon the weather, therefore with good management, quality seedlings can be ready in quantity for any anticipated outplanting date.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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The objective of this study was to evaluate eedling growth from greenhouse, containerized ulture using supplemental photoperiod, carbon ioxide, and fertilizer topdressing treatments to btain seedlings suitable for outplanting at age ight months. Emphases were placed on seedling ize, biomass of tops and roots and morphology of he leaves.

PROCEDURES

Preliminary Study

In May, newly germinated white pine seedlings rom the same seed source were transplanted into illson-sized rootrainers and grown in three seprate environments. One treatment was 70 percent ath shade with natural photoperiod and daily temerature regimes. The other two groups of seedings were placed in the greenhouse with one treatent receiving enough supplemental light to comrise a daily photoperiod of 18 hours. The third reatment was natural photoperiod within the greenouse environment. All seedlings were fertilized 23-19-17) at 10-day intervals after they had beome established.

At age 7 months, 35 seedlings selected at andom from each group were harvested and analyzed or growth and biomass variables. For comparison, 5 seedlings were selected at random from each of nursery treatments at the Pinson Nursery; one roup had been spring-seeded with stratified seed nd those seedlings were about 8 months old, while he second group of 12 month old seedlings had een fall-seeded relying upon natural temperature nd moisture regimes to break seed dormancy. Other han the differing seed schedules, all seedlings t Pinson were grown with standard operational rocedures, including shading, watering, fertilizng, and weeding.

Greenhouse Culture Study

Based upon information derived from the preiminary tests, a study was established in the reenhouse during October, 1979, to test the ffectiveness of selected culture techniques for rowing white pine seedlings that would be suitble for outplanting at 8 months of age or less. upplemental light, carbon dioxide, and fertiizers were incorporated within the randomized lock experimental design.

The study was conducted in two greenhouses, e of which was equipped with a carbon dioxide enerator fueled by propane. In the absence of rbon dioxide monitoring equipment sensitive to 00 ppm concentrations, the carbon dioxide genrator was operated according to manufactuers ggested levels for 6 hours each night. To mainain acceptable day-time temperatures, the carbon ioxide house was usually vented each morning, hereby negating any effect of supplemental carbon ioxide until the next cycle.

Supplemental light was provided in each house with a bank of six Gro-lux, fluorescent lamps over each bench on a continuous photoperiod. The intention was to provide growth stimulation and not just to retard bud set. As a matter of fact, the light controls, i.e., natural photoperiod treatment, received a one-hour interruption of the dark period with enough light to prevent bud dormancy and maintain active seedling growth.

All seedlings received soluble fertilizer (20-20-20) incorporated with regular waterings on a 10-day interval. Slow-release fertilizer had not been added to the mix previously. In addition, half of the seedlings in each carbon dioxide and light treatment also received a topdressing of 25-10-10 at 20-day intervals.

At seven months of age, the seedlings were harvested. Height, root collar diameter plus biomass of roots and tops were measured and analyzed.

RESULTS

Preliminary study

Seedling sizes were encouraging for growing white pine in containerized, greenhouse culture (table 1). In most cases, the extra light of the 18-hour photoperiod helped produce seedlings at 7 months of age that were the same size or larger than nursery-grown seedlings at 12 months of age. The 8-month old nursery-grown seedlings were clearly the smallest of all seedlings.

Height growth was greater in the 12-month nursery treatment than in the supplemental light treatment. Root collar diameter and biomass were significantly increased by the supplemental light treatment. Biomass estimates were especially noteworthy for the 18-hour photoperiod, for those seedlings were significantly larger than any others and the balance of roots and tops was good.

In addition to those easily measured variables, there were several other important differences. For example, foliage color on the 18-hour photoperiod seedlings was dark, blue-green and healthy. Foliage on the other treatments was yellow-green and some leaves were dying. Most seedlings growing under natural photoperiod had dormant terminal buds, but the 18-hour photoperiod seedlings were still actively growing when they were harvested.

Perhaps the most important difference was the abundance of secondary leaves on the 18-hour photoperiod seedlings. These seedlings started developing secondary leaves from buds at the axils of the primary leaves shortly after they received the extended photoperiod. By the time of harvest, the secondary leaves were fully developed and covered most of the length of the epicotyl with the primary leaves. Considerable photosynthetic surface

Table 1.--Mean sizes of eastern white pine seedlings after growing in rootrainer culture or nursery beds for varying periods.

Treatment	Height	Root Collar Diameter	Biomass Roots	Biomass Tops
	cm	mm	g	g
Greenhouse				
18-hour photoperiod	8.1b[1]	1.7a	0.42	0.50a
natural photoperiod	6.8c	1.4c	0.37	0.33c
Outside-lath shade				
natural photoperiod	7.9b	1.5b	0.38	0.39b
Pinson Nursery				
fall seeding	9.5a	1.6a	none	0.44b
spring seeding	5.3d	1.2d	none	0.27c

[1] Lower case letters refer to those means that were grouped as equal at the 0.05 probability level with Duncan's Multiple Range Test.

area was manifested through this proliferation of of secondary leaf tissue.

Greenhouse Culture Study

Adjusted means for the growth variables are presented in table 2. Height growth was significantly and adversely affected by fertilizer topdressing and carbon dioxide treatments (P>0.01). The tallest seedlings were grown without extra carbon dioxide and without fertilizer topdressings. The extra light, carbon dioxide, and fertilizer topdressing treatments produced the shortest seedlings.

Root collar diameter was statistically greater (P>0.01) for seedlings receiving extra light, but it was statistically the same for all other treatments at seven months. Carbon dioxide had a positive effect, but it was not significant (P>0.05).

Biomass can be an important indication of anticipated outplanting success assuming height and diameter are adequate. The influence of supplemental light was strongly manifested with the biomass variables; fresh and dry weights of tops and roots were highly significant (P>0.01). Neither supplemental carbon dioxide nor fertilizers had any significantly positive effects on fresh

Table 2.--Growth of eastern white pine seedlings using light, carbon dioxide, and fertilization treatments for seven months in a greenhouse.

Treatment	Growth Variable Height	Root Collar Diameter	Top Biomass fresh	Top Biomass dry	Root Biomass fresh	Root Biomass dry	Root/Shoot Ratio
	cm	mm	g	g	g	g	%
Photoperiod							
Continuous	7.3	2.3	2.851	0.843	0.767	0.203	25.4
Natural	7.4	1.7	1.394	0.382	0.347	0.070	19.1
Carbon Dioxide							
Supplemental	7.1	2.0	2.106	0.638	0.633	0.154	25.3
Natural	7.6	1.9	2.138	0.588	0.481	0.124	20.9
Fertilizer							
Base (20-20-20)	7.5	2.0	2.096	0.596	0.617	0.150	24.1
Base plus topdressing (25-10-10)	7.2	2.0	2.148	0.630	0.497	0.128	20.3

r dry weights of seedling tops. The supplemental
arbon dioxide treatment significantly (P>0.01)
ncreased root weights. Fertilizer topdressings
ecreased root fresh and dry weights (P>0.05),
hile top biomass remained unchanged. The effect
as decreased root/shoot balance.

Root/shoot ratio, as calculated from dry
eights, showed supplemental light and carbon
ioxide to have significant benefits to a well-
alanced seedling. In both cases roots were bet-
er developed when the seedlings were grown with
upplemental carbon dioxide and a continuous photo-
eriod. Fertilizer topdressings reduced the root/
hoot balance through a decrease in root weight
nd an increase in top weight.

DISCUSSION

The worth of any seedling culture technique
ay not always be found in growth statistics at
he end of the culture period, rather the ulti-
ate test will be the success of the outplanting
peration for which the seedlings were grown.
owever, some good inferences about outplanting
uccess can be gleaned from seedling growth per-
ormances during greenhouse culture.

Quality white pine seedlings for outplanting
hould have enough height and diameter to survive
he outplanting operation and still be in a favor-
ble position to grow with the competing vegeta-
ion. Enough energy reserves must be present to
ustain growth processes while seedling roots
ecome established. The foliage should begin
hotosynthesis quickly, therefore a good mixture
f primary and secondary leaves with healthy color
s required. Were seedlings with such character-
stics produced in this experiment? Some of the
reatments were quite effective, but not all of
he answers are available yet.

Light had a positive growth influence beyond
he requirement to interrupt the dark period in
rder to maintain active growth during winter
onths. Diameter and biomass, both of which
eflect the extent that photosynthate production
nd accumulation results in secondary growth, were
ignificantly enhanced by extra light, either an
8-hour or a continuous photoperiod. Although
eedlings were not rapidly elongating tops or
oots, the cambium was using photosynthate to
hicken the stem and secondary leaves were pro-
uced from buds that broke dormancy as a result
f the extra light. Perhaps most significantly,
he root biomass was increased, indicating storage
f carbohydrates and other energy-rich compounds
hat would keep the seedling growing vigorously
uring that critical time of field establishment.

The influence of supplemental carbon dioxide
as positive for seedling diameter and biomass
rowth. The appearance of seedlings in the carbon
ioxide greenhouse, especially those receiving
upplemental light, gave further indication of
heir suitability for outplanting. They had good foliage color and the secondary leaves were well-developed along the entire stem. Although data analyses did not reveal a light and carbon dioxide interaction, expectations of outplanting success are great for those seedlings receiving both supplemental light and carbon dioxide. Increasing propane costs may negate the reality of growth benefits derived in carbon dioxide enriched atmospheres, however.

Topdressings of 25-10-10 once every 20 days produced positive growth responses to seedling tops and adversely affected root biomass and seedling height growth. Tops were direct recipients of the fertilizer mist and they apparently made immediate use of the nutrients. Translocation of photosynthate into the roots was not a factor as reflected by root biomass. Neither was there elongation of primary tissues. Without separate biomass analyses of leaves and stems, it was impossible to locate the source of biomass accumulation in the seedling tops.

Other questions are yet to be addressed in this greenhouse culture technique. What will be the effects on seedling growth of differing container sizes, differing growing media, slow-release fertilizers, ectomycorrhizal symbionts, and how about higher concentrations of carbon dioxide, different fertilizer formulations and application timing? Obviously we are just getting started.

SPOT SEEDING IS EFFECTIVE AND INEXPENSIVE FOR REFORESTING SMALL ACREAGES[1]

T. E. Campbell[2]

Abstract.--First-year establishment of one or two seedlings on 1,000 spots per acre produced fully stocked stands of slash and loblolly pines on both medium and poor quality sites by age 10. Starting with five and nine seedlings per spot also produced fully stocked stands but resulted in slightly reduced height and diameter growth.

Direct seeding is a successful and widely accepted method of regenerating southern pines. Though broadcast sowing from aircraft is generally used on large areas, spot sowing by hand is an excellent alternative for small tracts or where broadcasting is impractical (Lohrey 1970). Spot seeding requires only 1/3 to 1/2 the seed used in broadcast sowing and permits better control of stocking and spacing than is possible with broadcasting. It is also cheaper, faster, and less laborious than hand planting nursery seedlings. Spot seeding is especially suitable for small landowners who must keep out-of-pocket expenses to a minimum (Mann and Burns 1965). But when multiple seeds are dropped on a spot to insure maximum stocking, several seedlings often result. Such clustering is not a serious problem up to age 3 for species that readily express dominance, but little is known about its effect beyond that age (Campbell 1964).

This study was designed to show how many seedlings are needed per spot to insure adequate stocking and how multiple trees per spot affect growth. Slash (*Pinus elliottii* Engelm. *elliottii*) and loblolly (*P. taeda* L.) pines were established with one, two, five, and nine seedlings per spot on both medium and poor quality sites. This paper reports measurements of the study at 10 years.

METHODS

The four seedling densities were established on 0.1-acre square plots and were replicated four times in a randomized block design for two species on two sites.

The site judged to be of medium quality is a Ruston fine sandy loam; surface soil is brown in color, about 8 inches deep, and overlays a red sandy clay loam subsoil. Surface and internal drainage are good. The poor quality site is on a Cadeville sandy loam; surface soil is gray in color, is about 6 inches deep, and is underlain by a slowly permeable reddish brown clay. Surface drainage is adequate. Scattered second-growth longleaf pines and many scrub hardwoods covered both sites. Before the study was install pines were removed and hardwoods were injected wi herbicides.

Seed spots were prepared at 6.6-ft square spacing (1,000 per acre or 100 per plot)--leaves and duff were scraped away with a fire rake, and mineral soil was exposed. Spots were hand sown with about 20 stratified, repellent-treated seeds to insure heavy stocking on each spot. Seeds wer pressed into mineral soil with the seeder's boot. After one complete growing season, spots were thinned to appropriate densities of the tallest seedlings per spot.

The central 36 spots on each treatment plot were measured at age 10. Seedling survival was determined from the difference between total tree counts on all 36 spots at ages 2 and 10. Spot stocking was the proportion of spots stocked with one or more seedlings and trees per spot was the average per stocked spot. Total height and d.b.h were measured for the tallest tree on each of 36 spots, and for every tree on nine central spots within the 36 measurement spots. Heights were measured to the nearest 1-ft with a telescoping pole and d.b.h. to the nearest 0.1-inch with a diameter tape. For each measurement variable, differences between spot densities were tested for significance at the .05 level by analysis of variance. Separate analyses were made for each species on each site. Experimental design did not permit statistical comparison of species or sites.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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RESULTS AND DISCUSSION

Survival

Mean survival ranged from 92.5 percent for loblolly single-tree spots on the medium site to 60.7 percent for slash nine-tree spots on the poor site (table 1). On the medium site, single trees of both species survived better than trees on plots with nine per spot. Three single-tree plots on the medium site had 100 percent survival; one was slash pine and the other two were loblolly. On the poor site, seed spot density did not affect survival of either species.

Table 1.--Mean survival from age 2 to 10[1]

Trees per spot after thinning	Slash pine Medium site	Slash pine Poor site	Loblolly pine Medium site	Loblolly pine Poor site
Number	Percent			
1	89.2a	72.9a	92.5a	78.7a
2	84.7ab	76.5a	76.3bc	89.1a
5	83.7ab	63.8a	86.9ab	88.5a
9	68.6b	60.7a	62.6c	79.2a

[1] By column, treatment means not followed by the same letter are significantly different at the 5-percent level.

Spot Stocking

At age 10 on both sites, slash pine thinned to five and nine trees per spot had higher stocking rates than plots with one or two trees per spot (table 2). The trend was similar, but not so clearcut, for loblolly--the five-tree treatment on a medium site and the nine-tree treatment on a poor site both had better stocking than the one- and two-tree treatments.

These results seem reasonable since spots with more trees growing on a better site had an initial advantage. But single-tree spots provided an excellent stand of 727 (625 to 833) well-spaced 10-year-old trees per acre.

Plots thinned to two seedlings per spot at age 2 still averaged 1.6 and 1.7 trees 8 years later, or 84 percent of original stocking. As expected, survival on denser spots was proportionately less because of greater competition for growing space. Five-tree spots averaged 2.9 to 4.1 ten-year-olds, and nine-tree spots averaged 3.9 to 5.2.

Tree Size

The tallest slash pine per spot on the medium site at the highest density averaged 23 ft. It was significantly shorter than the average tree on one- and two-tree spots, but the difference was only 2 ft (table 3). Single loblolly pines on the poor site averaged 28 ft while the tallest tree on double spots averaged 24 ft, but the difference was probably not caused by the extra tree.

Height differences between the tallest and second tallest trees on multiple-tree spots ranged from 2.1 to 6.8 ft by treatment. These two extremes were both loblolly pines on the medium site; the greatest difference occurred on two-tree spots and the least difference on nine-tree spots. The other 10 combinations of density, species, and site had average differences of only 2.5 to 4.1 ft. Dominants in all combinations of species, site, and multiple trees are probably firmly established, with enough height advantage to maintain their superiority. And as trees age, spot density will probably influence height differences more because growth of suppressed and subordinate trees will slow.

Seed spot density in three of the four species-site combinations significantly influenced d.b.h. Single slash pines on the medium site averaged 4.6 inches, and single loblolly pines on the poor site averaged 4.4 inches. Both were larger than dominant trees on all multiple-tree spots for those treatments (table 3). Also, single and double trees were larger than those on five- and nine-tree spots for loblolly on the medium site. Single trees were up to 1.4 inches larger than dominant trees on five- and nine-tree spots because of clustered competition. The tallest tree on a multiple-tree spot was not always the largest in d.b.h., however. Occasionally, a codominant or intermediate tree had greater d.b.h., but only the tallest trees were being compared.

The tallest and second tallest tree per multiple-tree spot differed significantly in d.b.h. for both species on the medium site--differences were greater for doubles than for five- and nine-tree spots. Neither species had significant differences on the poor site; so trees apparently express dominance more readily on a good site than on a poor site.

RECOMMENDATIONS

Mann and Burns (1965) recommend the small landowner sow six seeds on each of 1,000 prepared spots per acre. But their studies were concerned only with seedling establishment. Ten-year results of this study support their recommendation, based on the well-established rule-of-thumb used in direct seeding that one seedling is obtained from each three seeds sown. Five seeds per spot will, under normal circumstances, establish at least one seedling on most spots while four or five will be a rarity. The overall average will be one to three seedlings per spot.

Starting with 1,000 spots per acre, this study yielded from 625 to 902 spots stocked with one or two trees at age 10. Though spot densities of five or nine seedlings significantly improved the proportion of spots still stocked, an average of 758 well-spaced spots per acre with one or two trees each is an excellent stand. Land managers who prefer fewer stocked spots per acre could sow proportionately fewer spots.

Growth rates were also better with fewer trees per spot. Though spot density had only a small influence on heights of the dominants in a cluster, height growth of one or two trees per spot was slightly better than height growth in more densely stocked stands. Diameter growth of dominants on the less dense spots showed a decided advantage of up to 1.4 inches in 10 years.

Because of these advantages, higher spot densities are undesirable, but not completely unacceptable. Up to nine seedlings per spot yielded higher per-acre spot stocking, survival was adequate, individual tree dominance was established early, and height growth was reduced only minimally. Reduction in diameter growth was greater, but volume-per-acre differences should be made up in the extra stems.

Results from this study show conclusively that spot seeding is a practical alternative to planting nursery seedlings. And it is especially suited to the small-woodlot owner. He can do the job in his spare time, use tools available around the farm such as a fire rake or potato hoe to prepare the spots, and do it with less effort in less time at less cost than planting. Raking a spot to mineral soil and dropping five seeds is far less laborious than opening a slit with a dibble, properly placing the seedling roots, and closing the slit. Sowing a spot requires 25 to 50 percent less time than planting a seedling. And at local 1979 prices, sowing 1,000 spots with five loblolly seeds instead of planting 1,000 seedlings would save $10.40. These savings in effort, time, and money make spot seeding an attractive establishment method for farmers, 4-H Club students, and landowners with small, understocked tracts.

LITERATURE CITED

Campbell, Thomas E.
1964. Development of slash pine on seed spots. J. For. 62:821-822.

Lohrey, Richard E.
1970. Spot seeding slash and loblolly pines. For. Farmer 29(12):12, 18.

Mann, W. F., Jr., and E. B. Burns.
1965. Direct seeding for the small landowner. For. Farmer 25(3):6-7, 14.

differences between spot densities were tested for significance at the .05 level by analysis of variance. Separate analyses were made for each species on each site. Experimental design did not permit statistical comparison of species or sites.

RESULTS AND DISCUSSION

Survival

Mean survival ranged from 92.5 percent for loblolly single-tree spots on the medium site to 60.7 percent for slash nine-tree spots on the poor site (table 1). On the medium site, single trees of both species survived better than trees on plots with nine per spot. Three single-tree plots on the medium site had 100 percent survival; one was slash pine and the other two were loblolly. On the poor site, seed spot density did not affect survival of either species.

Table 1.--Mean survival from age 2 to 10[1]

Trees per spot after thinning	Slash pine Medium site	Slash pine Poor site	Loblolly pine Medium site	Loblolly pine Poor site
Number	Percent			
1	89.2a	72.9a	92.5a	78.7a
2	84.7ab	76.5a	76.3bc	89.1a
5	83.7ab	63.8a	86.9ab	88.5a
9	68.6b	60.7a	62.6c	79.2a

[1] By column, treatment means not followed by the same letter are significantly different at the 5-percent level.

Spot Stocking

At age 10 on both sites, slash pine thinned to five and nine trees per spot had higher stocking rates than plots with one or two trees per spot (table 2). The trend was similar, but not so clearcut, for loblolly--the five-tree treatment on a medium site and the nine-tree treatment on a poor site both had better stocking than the one- and two-tree treatments.

These results seem reasonable since spots with more trees growing on a better site had an initial advantage. But single-tree spots provided an excellent stand of 727 (625 to 833) well-spaced 10-year-old trees per acre.

Plots thinned to two seedlings per spot at age 2 still averaged 1.6 and 1.7 trees 8 years later, or 84 percent of original stocking. As expected, survival on denser spots was proportionately less because of greater competition for growing space. Five-tree spots averaged 2.9 to 4.1 ten-year-olds, and nine-tree spots averaged 3.9 to 5.2.

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LITERATURE CITED

Campbell, Thomas E.
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1965. Direct seeding for the small landowner. For. Farmer 25(3):6-7, 14.

Table 2.--Stocked spots per acre from 1,000 seeded, and mean trees per stocked spot at age 10

Trees per spot after thinning	Stocked spots[1]				Trees per spot			
	Slash pine		Loblolly pine		Slash pine		Loblolly pine	
	Medium site	Poor site	Medium site	Poor site	Medium site	Poor site	Medium site	Poor site
	Number							
1	792b	625c	833b	660c	1.0	1.0	1.0	1.0
2	902b	729b	764b	757bc	1.7	1.6	1.7	1.7
5	986a	861a	965a	854ab	3.9	2.9	4.1	3.5
9	972a	910a	896ab	909a	5.2	3.9	4.8	5.1

[1] By column, treatment means not followed by the same letter are significantly different at the 5-percent level.

Table 3.--Mean total height and mean d.b.h. of the tallest tree per stocked spot at age 10[1]

Trees per spot after thinning	Height				D.b.h.			
	Slash pine		Loblolly pine		Slash pine		Loblolly pine	
	Medium site	Poor site	Medium site	Poor site	Medium site	Poor site	Medium site	Poor site
Number	Feet				Inches			
1	25a	17a	27a	28a	4.6a	2.8a	4.3a	4.4a
2	25a	19a	28a	24b	4.1b	3.1a	4.1a	3.4b
5	24ab	19a	26a	26ab	3.2c	2.9a	3.3b	3.5b
9	23b	18a	26a	25ab	3.2c	2.7a	3.5b	3.2b

[1] By column, treatment means not followed by the same letter are significantly different at the 5-percent level.

PRESCRIBED BURNING BY AERIAL IGNITION[1]

Dane Roten[2]

Abstract.--The N.C. Division of Forest Resources is utilizing a Mark II aerial ignition dispenser developed by the Pacific Forest Research Center in Victoria, British Columbia, to conduct prescribed burnings. The dispenser is mounted in a UH1B helicopter. The aerial ignition device (AID) is a polystyrene ball containing potassium permanganate. Ignition occurs in 25 to 30 seconds after the AID is injected with an ethylene glycol solution. Average cost for firing for hazard reduction and silvicultural burning is $1.31 per acre and $1.57 for site preparation burning.

The use of aerial ignition in prescribed burning was first developed in Australia during the mid-sixties for hazard reduction purposes. An automated machine mounted in a fix-winged aircraft was used to eject incendiary capsules at a predetermined spacing along parallel flight lines over the area to be burned. An aircraft was capable of safely burning up to 30,000 acres in a single day (Dept. of Forestry, Western Australia).

The N.C. Division of Forest Resources first became aware of aerial ignition burning techniques while hosting an Australian fire study tour during 1971. In 1975, I had the opportunity to participate in a return fire study tour. While we did not see an aerial ignition prescribed burn, the results were very obvious. Hazardous forest fuel accumulation in the commercial eucalypt forest, a condition which often resulted in large destructive fires, had been practically eliminated.

In 1977, the N.C. Division of Forest Resources, in cooperation with Weyerhaeuser Company, borrowed a Mark II aerial ignition dispenser from Premo Plastics located in Victoria, British Columbia, to conduct aerial ignition studies. The results were so impressive that a Mark II dispenser was purchased and installed on a UH1B helicopter. Since the initial purchase, two additional dispensers have been obtained.

The Mark II aerial ignition dispenser was developed by the Pacific Forest Research Center in Victoria, British Columbia. It is manufactured and sold by Premo Plastics Engineering Ltd., 863 Viewfield Road, Victoria, British Columbia. The dispenser has four feed chutes through which aerial ignition devices (AIDs) are dispensed. Each chute is capable of dispensing one AID per second. The chutes may be operated in any combination of one to four. The number of chutes activiated and the speed of the helicopter determines the ignition spacing along the flight line. The aerial ignition device (AID) is a high impact polystyrene ball 1.25 inches in diameter. It contains 3.5 grams of potassium permanganate. As the AIDs are dispensed through the chutes, they are automatically injected by a hollow steel needle with 1 ml. of 50% ethylene glycol solution. The chemical reaction normally produces (Sain 1979) ignition in about 25 to 30 seconds.

The objectives of our aerial ignition program are to expand prescribed burning capabilities for hazard reduction, site preparation, and silviculture burnings and to develop techniques for burning-out and backfiring in the control of wildfires.

The procedure most often used in aerial ignition for hazard reduction and silvicultural burning is to fire the base line downwind and allow the fire to back a safe distance. The base line is usually fired by hand; however, it may be red by aerial ignition if readily visible from e helicopter. When the base line is secure, ight lines are flown upwind at a predetermined acing. This procedure keeps the helicopter t of the smoke and results in a backing fire ould a breakdown occur. Other methods of ring may be desirable when the base line is not rpendicular to the wind direction.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

[2] Dane Roten, Senior Staff Forester, Fire Control Staff, N.C. Division of Forest Resources, P.O. Box 27687, Raleigh, North Carolina 27611.

Studies conducted by the N.C. Division of rest Resources indicate that the spacing of ot fires determines the intensity of the burn thin certain limits. These observations dicate that close spacing results in a shorter rn-out time with more heat being released per it of time and consequently resulting in a re intense burn. These observations concur th research done by Sackett which indicated at close spacing (Sackett 1968) produced more tensive burns. Optimum spacing to maximize sults and to minimize costs in hazard duction and silviculture burnings appears to about two chains by two chains when burning der Division of Forest Resources's guidelines. en stand conditions are such that a more tense burn is required either to eliminate ditional fuel in hazard reduction or to kill rger diameter hardwoods for silviculture rposes, the spacing may be reduced. During rginal burning conditions, closer spacing may used to intensify the burn in stands that herwise would be difficult to burn under isting weather conditions.

The Mark II dispenser transported by a 1B helicopter has the capability of firing proximately 1,000 acres per hour when flight nes are spaced one chain apart. Production n be increased by increasing the distance tween flight lines.

Firing techniques and ignition spacing may ry considerably in site preparation burning. e various techniques of strip spot firing, rimeter firing, key hole firing, plus the chnique of starting in the center and firing tward in increasing circles may all be used ccessfully. As with hazard reduction firing, e burn-out time can be reduced and the fire tensity increased by reducing the spacing tween spot fire ignitions. Very strong nvection can be formed in heavy fuels by rapid ose spaced firing techniques which produce fects similar to mass ignition.

In an effort to minimize stand damage when rning in an existing stand, we recommend strict herence to the guidelines established by ckett. Research done by Sackett indicates at the optimum relative humidity range for a ccessful burn is 30% to 60% and the optimum nd (Sackett 1968) between one and five miles per hour. A rule-of-thumb for converting open 20 foot standard wind velocities to in-woods velocities is: In closed canopies - 10% of open wind velocity, in open stands such as natural longleaf - 25% of open wind velocity. As a guide, we have used 60°F as an upper temperature limit for winter hazard reduction burning. These guides are conservative when burning in more mature pine stands; however, they are realistic when burning in younger pine plantations.

The N.C. Division of Forest Resources does contract aerial ignition for the forest land of the State. Prices are graduated depending upon the size of the area to be burned. The charges range from $5.00 per acre for tracts less than 30 acres down to $1.50 per acre for tracts over 1,000 acres. These charges cover the cost of AIDs (10¢ each), operating cost of the UH1B helicopter ($130/hr.), and the cost of personnel and equipment required to execute the burn. Additional charges are made for line construction. These charges vary from $75 per mile for plowed lines in existing stands to $190 for bladed lines in site prepared areas. Our average cost for AIDs and helicopter operation for the past year was $1.31 per acre for hazard reduction and silviculture burns and $1.57 per acre for site preparation burns.

Last year we burned 12,148 acres for hazard reduction, silvicultural purposes and wildlife habitat improvement, and 5,873 acres for site preparation for a total of 18,021 acres. We have a need to burn 200,000 acres annually for hazard reduction and silviculture purposes. While we do not anticipate ever having the capability to completely fulfill this need, we do hope to develop private contractors capable of providing this service to the large industrial landowners.

LITERATURE CITED

Department of Forestry, Western Australia.
Forestry in Western Australia.
Sackett, Stephen S.
1968. A field trial for regulating prescribed fire intensities. Fire Control Notes 29 (3): 5-6.
Sain, James
1979. First year evaluation of aerial ignition for prescribed burning and wildfire control. NCFS Forestry Note, No. 39.

TIMBER AND WILDLIFE IMPLICATIONS OF FIRE IN YOUNG UPLAND HARDWOODS[1]

Jimmy C. Huntley and Charles E. McGee[2]

Abstract.--Upland hardwood stands on good sites were burned after clearcutting to determine the effects of fire on species density, frequency, composition, and dominance. One fire in 4- to 6-year-old stands did not substantially alter a trend whereby oak was replaced by other species. The stands recovered rapidly from the fires and loss of growth and stem quality appeared to be small. Increased browse density and herbaceous coverage improved wildlife habitat.

A particularly vexing problem in upland hardwood management has been the inability to adequately regenerate oak on good sites. Recognizing this problem, the 1979 John S. Wright Forestry Conference at Purdue University was entitled "Regenerating oaks in upland hardwood forests." In a recent research evaluation the Hardwood Research Council described the regeneration of oak problem as "most urgent" (McLintock 1979).

A decline of oak on good sites will have a substantial impact on timber production through the loss of high quality oak veneer and sawlogs. On poorer sites--where oak seems to regenerate readily--timber is often poor quality and suitable only for low-value products.

The greatest impact of oak loss may be upon wildlife because oak is an important food source for many species. Van Dersal (1940) reported that 186 different kinds of wildlife feed on oak, and that acorns were a preferred or staple food for a great number. Hamilton (1941) reported that deer mice, white-footed mice, and red-backed voles often ate large quantities of mast, particularly beechnut and acorns. (Scientific and common names of all species are included in the appendix.) From an intensive review of food habit studies, Martin, Zin, and Nelson (1951) drew the following conclusions: In the Southeast, oak ranked first in percentage of use by wildlife and only Panicum spp. and corn were used by more species. In the eastern United States, oak comprised over 25 percent of the diet of wood duck, wild turkey, blue jay, black bear, raccoon, lesser prairie chicken, eastern fox squirrel, gray squirrel, and white-tailed deer. Oak comprised over 5 percent of the diet of ruffed grouse, bobwhite quail, common grackle, white-breasted nuthatch, brown thrasher, tufted titmouse, rufous-sided towhee, red-bellied woodpecker, red-headed woodpecker, flying squirrel, eastern chipmunk, and white footed mouse.

Recent studies have documented the loss of oak from good hardwood sites. McGee and Hooper (1970, 1975) found that a stand of high quality mixed hardwoods in the southern Appalachians, which had been mostly oak with prolific advance reproduction, converted quickly to yellow-poplar following clearcutting. In a summary of research in the central Appalachians, Trimble (1973) and Smith (1979) concluded that neither selection-cutting nor clearcutting adequately regenerated oak on excellent sites (site index 80). Yellow-poplar was a major component of regeneration on such sites. They found that on fair oak sites (site index 60), clearcutting regenerated oak better than selection-cutting. Merz and Boyce (1958) found in southern Ohio that cutting intensity may have a greater impact on oak regeneration than site quality. However, the general trend on good sites has been the loss of oak after either selection-cutting or clearcutting.

Recent hardwood management guidelines suggest that the perpetuation of oak in new stands probably depends on the presence of sufficient dvance reproduction in the harvested stand Roach and Gingrich 1968, Trimble 1973, Sander 977). Stump sprouts should be considered a upplement to advance reproduction. Merritt 1979) considered lack of advance reproduction a ajor problem throughout most of the oak-hickory ange. But he pointed out that there aren't nough answers to oak regeneration problems. lthough the shelterwood system seems theoreti-ally ideal for increasing oak reproduction, esearch with shelterwood cuttings has been isappointing (Sander 1979).

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

[2] Wildlife Biologist and Principal Silviculturist, respectively, at the Sewanee Silviculture Laboratory, maintained at Sewanee, Tennessee, by the Southern Forest Experiment Station, Forest Service-USDA, in cooperation with the University of the South.

If the various cutting methods don't enable ak to regenerate adequately, then the question rises: How did present oak stands become estab-ished? McGee (1979) points out that today's nvironment is different from 50 or 100 years ago. he passing of American chestnut and widespread orest fires were suggested as factors that may ave affected the establishment of oak stands.

Loss of American chestnut probably had an ffect similar to timber harvesting. Depending n the dominance and distribution of chestnut in he stand, different types of cutting would have een simulated. Since different cutting practices ave not improved oak regeneration, the role of ire in the origin of oak stands seem worthy of onsideration.

Garren (1943), in a review of fire effects n southeastern vegetation said fire was of major cological importance. In some parts of the egion, fire seems to exert as much influence as limate and soil in determining the dominant type f vegetation. The role of fire in maintaining any conifer forest types in the eastern United tates has been long recognized (Little and Moore 949). There is much speculation but little vidence of fire's role in the establishment of ak stands (Merritt 1979, Sander 1977). Stephens nd Waggoner (1980) think that dominance of oak n Connecticut is likely the result of both fire nd repeated clearcutting for fuelwood and char-oal production, as well as the loss of chestnut.

The need to determine if fire actually layed a major role in establishing oak on good ites led to this study. It reports on the effects f burning young upland hardwood stands that had eveloped after clearcutting. The study's broad bjective is to determine if fire affects the pecies composition and dominance of young hard-ood stands. A specific interest is to determine f single burns applied at different seasons in-rease oak reproduction on good sites. The effect f fire on yellow-poplar is of particular interest ince yellow-poplar is often a major competitor o oak on good sites in the southern Appalachian untain and Plateau regions.

This exploratory study lacks replication and s limited to a comparison of stand development n two areas burned in the spring, one area burned in the fall, and one unburned area. The aim is to formulate rather than test hypotheses concerning the role of fire in hardwood regeneration. Valuable basic data are provided on fire effects in young hardwood stands in a region where such data were lacking. Information gained can form the basis for future, more intensive research. Earlier reported results (McGee 1979, 1980) emphasized timber-related values while this report considers both timber and wildlife implications.

LOCATION AND DESCRIPTION OF STUDY AREA

In cooperation with Alabama National Forest personnel, four study areas were established in northern Alabama on the William B. Bankhead National Forest. All areas are at least 2 ha (5 acres) and are on slopes between the sandstone top of the Cumberland Plateau and limestone valleys to the north. Elevation relief is about 105 m (350 ft.), ranging from 300 m (1,000 ft.) on top of the plateau to 195 m (650 ft.) in the valleys. Soils lie mostly over limestone but are stongly influenced by sandstone and shale colluvium from the plateau top.

Areas 1, 2, and 3 are within the same stand and are contiguous. Aspect ranges from east to northeast in area 3, northeast to north in area 1, and north to west in area 2. Areas 1 and 3 are adjacent and quite similar except area 3 is farther upslope. Both are good hardwood sites where more mesic species might compete heavily with oaks. Area 2 is a slightly poorer site due to warmer aspect and less protection from surrounding terrain. Oaks were expected to compete well with other species on this site. Area 4 is 19.3 km (12 miles) east of the other three areas. Area 4 is on a north facing slope above a branch of Indian Creek. The creek has eroded through the sandstone cap of the plateau top and formed steep bluffs to the north and east. As a result this area, especially the mid and lower slope, is well protected and the most mesic of all areas. Area 4 is similar to areas 1 and 3.

Prior to harvest each area supported sawtimber stands of mixed hardwoods. The stands were predominately oak with scattered yellow-poplar, white ash, hickory, and other species. The timber was good with numerous individual stems of high quality.

METHODS

Treatments

Harvest and site preparation followed prescribed national forest techniques. Merchantable timber in areas 1, 2, and 3 was harvested in autumn 1970, and all remaining stems 2.54 cm (1 in.) dbh and greater were injected with undiluted 2,4-D in autumn 1971. In area 4 timber was harvested in autumn 1973, and site similarly prepared in autumn 1975.

Area 1 was burned in April 1976, five growing seasons after harvest and four growing seasons after injection. Area 2 was burned in November 1976, six growing seasons after harvest and five growing seasons after injection. Area 4 was burned in March 1978, four growing seasons after harvest and two growing seasons after injection. Area 3 was not burned.

Fire intensity varied between and within all burns. The burn on area 1 was a strip head fire that was generally light and spotty. Twenty percent of the area was virtually burn-free and an additional 36 percent received a light burn with only the top loose layer of litter consumed. The fire was light due to high fuel moisture and partial greenup. As a result of low intensity and coverage many stems were not top-killed.

The burn on area 2 was also a strip head fire but coverage was good and intensity moderate with loose litter and other fine fuels consumed. All reproduction, except the largest, was top-killed. Area 4 was burned with a ring head fire. Coverage was excellent, the fire was intense, and all stems were top-killed.

Data Collection

Density and composition of all woody taxa, except lowbush blueberries and woody vines, were checked with a grid of permanent sampling points. Points were spaced 15 m (50 ft.) apart with two circular nested quadrats at each point. Woody stems greater than 1.4 m (4.5 ft.) in height were sampled with 40.5 m^2 (.01 acre) quadrats, and smaller stems were sampled with 4 m^2 (.001 acre) quadrats which, respectively, gives a 20 percent and 2 percent sampling intensity. Individual stems were recorded by species or in the case of hickory, elm, sumac, azalea, hawthorn, and plum by genera.

Initial inventories were made on all four areas prior to burning. Followup inventories were made yearly after each growing season. Because of different harvesting and burning dates, the number of years of data collection from each study area varies (table 1). Data through the 1979 growing season are included in this report.

Additional data were collected in 1979 to determine height and dominance of woody stems and coverage by herbaceous and vine species. Height and dominance was sampled by dividing each 40.5 m^2 density quadrat into quadrants and recording the species and height of the tallest woody stem in each quadrant. Therefore, 400 dominant stems were tallied for each .4 ha (1 a) sampled area.

Coverage by herbaceous species and woody vines was visually estimated on 1 m^2 (10.8 $ft.^2$) circular quadrats. One quadrat was located 1.5 m (5 ft.) to the right of each permanent sampling point. Field data were recorded by species or genera, but several taxa were grouped into various vegetative categories for data analysis.

Table 1.--Sequence of treatments and inventories on four areas used to study the effect of burning young hardwood stands on the southern Cumberland Plateau, William B. Bankhead National Forest, Alabama

	Treatments and Inventories							
Area Number	Harvest	Injection	Initial Inventory	Burned	Re-inventories[2]			
					1 yr.	2 yr.	3 yr.	4 yr.
1	Fall 1970	Fall 1971	Feb. 1976 (5)[1]	April 9, 1976 (5)[1]	Sept. 1976	Oct. 1977	Nov. 1978	Sept. 1979
2	Fall 1970	Fall 1971	Feb. 1976 (5)	Nov. 7, 1976 (6)	Oct. 1977	Nov. 1978	Oct. 1979	
3	Fall 1970	Fall 1971	March 1976 (5)	Not Burned	No Data	Oct. 1977	Nov. 1978	Sept. 1979
4	Fall 1973	Fall 1975	Oct. 1977 (4)	March 20, 1978 (4)	Nov. 1978	Sept. 1979		

[1] Numbers in parenthesis are age of stand in years.

[2] Re-inventories are referenced by the number of growing seasons since burning for areas 1, 2, and 4 and growing seasons since initial inventory for unburned area 3.

RESULTS

Density and Species Composition of Woody Stems

The densities reported below will be the number of stems per 0.4 ha (1 a). Reporting woody data in 2 size classes facilitates an understanding of stand structure.

Small Stems

On unburned area 3 the density of small stems (< 1.4 m in height) began decreasing after age 5, when the initial inventory was conducted. Two years after initial inventory density had decreased to 7,623 from 11,249. Although density increased to 13,749 four years after initial inventory, the increase was due to many very small seedlings, primarily red maple. Few of these were expected to survive. On all burned areas the density increased substantially the first year after burning and then generally began a decrease toward preburn levels. The initial increases were from 7,790 to 23,771 on area 1; 11,867 to 36,785 on area 2; and 18,749 to 31,234 on area 4. The increases were due primarily to sprouting from topkilled stems. After 1 year the number of sprouts on all areas began to decrease. But density on area 1, similar to area 3, was increased by the presence of many red maple seedlings. These two areas are contiguous with a red maple seed source in the surrounding forest and from a few residuals not killed during site preparation.

Although major shifts in species composition did not appear after burning, some changes were apparent. Despite being topkilled by fire, all hardwood species sprouted to some degree. However, a common characteristic of oaks on all areas was that northern red oak--the most preferred oak species--did not sprout as well as black, scarlet, white, or chestnut oak. Red maple sprouted vigorously and increased in relative importance on all areas. Yellow-poplar reacted differently between the areas. Immediately following the fires yellow-poplar increased on area 1 but decreased on areas 2 and 4. On area 4, where the fire was hot and reproduction smaller, many yellow-poplar were killed. Yellow-poplar ensity was very low on area 2 before the fire nd almost nonexistent 3 years later. The greatest hange on the unburned area was a large decrease n yellow-poplar. Density of small oaks also ecreased. Since all stems that become a member f the overstory in the final stand must grow into he larger size class (greater than 1.4 m), a more etailed discussion of density and composition hange is presented in that section of the report.

Smaller size stems were most available as rowse for white-tailed deer. Not only was browse uantity increased, browse quality was also mproved (Blair et al. 1980). Some of the more desirable browse such as red maple, blackgum, dogwood, white oak, and smooth hydrangea had the highest density increase. The increase was persistent and was 211, 171, and 67 percent greater, respectively, than pre-burning densities on area 1 four years after burning, on area 2 three years after burning, and on area 4 two years after burning. The initial percentage increase on area 4 was smaller because it was younger when burned.

Large Stems

Absolute Density.--Unburned area 3 is a good example of how a young stand of hardwoods will develop following silvicultural clearcutting. Density of large stems (greater than 1.4 m in height) reached a peak of 5,140 per 0.4 ha at age 7. Due to ingrowth from the smaller category, oak, yellow-poplar, red maple, hickory, and elm increased in density since the initial inventory at age 5. Black cherry and white ash increased very little. As expected, density of large stems decreased markedly the first year after burning.

The smallest percentage decrease was in area 1 where many large stems were not topkilled by the less intense fire. Stem density on all burned areas is now greater than preburn levels. For areas 1, 2, and 4, respectively, 4, 3, and 2 growing seasons after burning, large stem densities are 5,335; 4,717; and 5,822.

Relative Density.--Changes in species composition as stands age or as a result of a disturbance such as fire are more evident when comparing relative density than absolute density. Relative density presents density on a percentage basis rather than as actual number of stems (table 2). When comparing changes in relative density on the unburned area since initial inventory, the most apparent feature is the stability of species composition. From age 5 to age 9 if individual oak species are excluded, yellow-poplar had the greatest loss--from 17.7 percent to 14.7 percent. Red maple had the greatest increase--from 11.7 percent to 13.7 percent. Although oak totals changed little, differences within the oak group were evident. Northern red oak decreased substantially while black oak, scarlet oak, and white oak increased at just about the same rate.

There were some changes in relative density between preburn and postburn populations. The greatest changes after 4 years on area 1 was a decrease in yellow-poplar from 22.6 percent to 14.1 percent and an increase in red maple from 1.8 percent to 12.1 percent. On area 2, all major species decreased except chestnut oak and red maple. The major increase, from 17.5 percent to 31.0 percent 3 years after the burn, was in the miscellaneous hardwood category. Eighty percent of the stems in this category were small tree and shrubby species. On both areas 1 and 2, the relative

Table 2.--Relative density of woody stems greater than 1.4 m (4.5 ft.) in height at various ages of one unburned and three burned regeneration areas of upland hardwoods on the southern Cumberland Plateau, Bankhead National Forest, Alabama1/

Area and Year of Inventory2/	Species3/													
	All Oaks	NRO	BO	WO	CO	YP	BC	WA	HIC	RM	Elm	BG	DW	Misc. Hdws.
	Percent													
AREA 3 (Unburned)														
Initial	21.8	8.0	0.8	6.9	6.2	17.7	3.5	3.0	3.3	11.7	5.3	9.8	7.7	16.2
2 Years	20.1	4.4	3.7	6.2	5.8	14.4	3.0	2.7	2.9	13.5	5.1	9.1	10.5	18.8
4 Years	21.0	3.8	3.7	8.4	5.2	14.7	2.6	2.6	3.8	13.7	6.3	9.8	10.9	14.6
AREA 1														
Pre-burn	14.8	7.2	2.0	2.3	3.2	22.6	5.6	6.6	1.9	1.8	2.8	7.6	15.3	21.1
Burned Spring 1976														
1 Year	7.6	3.1	1.3	0.6	2.6	15.8	7.3	9.8	1.0	11.3	2.1	5.3	15.8	23.9
2 Years	8.9	3.8	1.2	1.0	2.9	14.1	7.0	8.7	0.9	12.5	1.6	5.2	14.0	27.1
4 Years	12.2	3.6	2.7	2.6	3.3	14.1	5.2	7.8	2.1	12.1	2.4	6.2	15.1	23.0
AREA 2														
Pre-burn	19.2	5.5	4.6	6.2	2.9	3.2	9.1	5.1	2.0	17.3	9.3	6.7	9.1	17.5
Burned Fall 1976														
1 Year	8.7	0.4	3.2	1.6	3.5	3.3	14.1	8.9	1.6	16.5	5.6	3.5	7.1	29.6
3 Years	14.4	1.3	3.3	5.0	4.8	1.2	8.0	4.8	1.9	19.2	5.3	5.8	8.1	31.0
AREA 4														
Pre-burn	6.8	1.8	0.2	0.9	3.9	6.7	2.3	1.5	2.4	10.5	0.7	2.8	9.1	55.3
Burned Spring 1978														
1 Year	10.8	2.6	1.2	0.8	6.3	8.4	5.7	2.6	1.0	9.0	0.4	5.6	2.8	53.1
2 Years	7.3	2.2	0.8	1.1	3.2	5.1	3.2	1.9	2.8	10.5	0.6	6.0	6.9	55.4

1/ Relative density = $\frac{\text{Density per species}}{\text{Total density}} \times 100$

2/ Years indicate the number of growing seasons since initial inventory on area 3 and since burning on the other areas; areas 1, 2, and 3 were 5 years old at first inventory and area 4 was 4 years old.

3/ NRO--northern red oak; BO--black oak, scarlet oak, southern red oak; WO--white oak; CO--chestnut oak; YP--yellow-poplar; BC--black cherry; WA--white ash; HIC--hickories; RM--red maple; Elm--elms; BG--blackgum; DW--dogwood; Misc. Hdws.--other trees plus shrubby species.

density of northern red oak was substantially reduced after burning. On area 4 the failure of one fire to alter species composition was most apparent. Only 2 years after burning the relative density of all species except blackgum was very similar to preburn levels.

In area 4 the percentage of miscellaneous hardwoods was very high. Sugar maple, American beech, black walnut, and cucumber tree, species characteristic of a mixed mesophytic forest, were present on this area but absent from the other areas. The major difference was that 2 species, eastern hophornbean and carolina buckthorn, were much more abundant on area 4. Eastern hophornbean comprised 20.5 percent of the total stand and was the most abundant single species. As age increases small tree species will be less able to dominate the stands.

Frequency

Frequency to indicate distribution of the various species is presented only for the large stems higher than 1.4 m (table 3). Burning generally had little long term effect on species distribution whether comparing preburn with postburn inventories or burned areas with the unburned area. An exception was an increase in red maple on area 1, which went from 15 percent before burning to 91 percent 4 years after burning. The red maple increase on the other areas was much smaller. Frequency of black oak and hickories increased with time on all areas. The largest decrease in frequency, 18 percent, occurred to northern red oak on area 2.

Table 3.--Frequency of woody stems greater than 1.4 m (4.5 ft.) in height at various ages of 1 unburned and 3 burned regeneration areas of upland hardwoods on the southern Cumberland Plateau, Bankhead National Forest, Alabama[1]

Area and Year of Inventory[2]	Species[3]													
	All Oaks	NRO	BO	WO	CO	YP	BC	WA	HIC	RM	Elm	BG	DW	Misc. Hdws.
	Percent													
AREA 3 (Unburned)														
Initial	90	71	23	62	58	83	71	50	46	85	40	79	92	98
2 Years	89	67	60	56	62	90	71	56	56	96	42	75	94	83
4 Years	92	71	60	56	64	83	69	56	62	96	48	83	88	88
AREA 1														
Pre-burn	89	74	38	42	42	88	86	59	44	15	48	77	97	97
Burned Spring 1976														
1 Year	70	44	30	17	41	80	79	59	24	73	30	56	82	79
2 Years	82	64	30	23	47	86	82	59	29	80	35	58	89	95
4 Years	91	73	59	41	56	88	82	62	54	91	45	76	95	97
AREA 2														
Pre-burn	88	57	52	54	21	46	84	62	36	87	67	74	77	92
Burned Fall 1976														
1 Year	57	5	28	16	18	21	62	43	15	56	36	34	44	80
3 Years	90	39	69	64	38	36	92	62	62	92	74	80	87	100
AREA 4														
Pre-burn	62	39	9	17	33	76	45	34	42	78	11	44	88	100
Burned Fall 1978														
1 Year	52	22	17	6	22	39	44	22	6	58	6	36	36	94
2 Years	76	39	30	22	33	69	58	41	56	81	17	70	78	98

[1] Frequency = $\frac{\text{Number of sample plots where species are present}}{\text{Total number of sample plots}} \times 100$

[2] Years indicate the number of growing seasons since initial inventory on area 3 and since burning on the other areas; areas 1, 2, and 3 were 5 years old at first inventory, and area 4 was 4 years old.

[3] NRO--northern red oak; BO--black oak, scarlet oak, southern red oak; WO--white oak; CO--chestnut oak; YP--yellow-poplar; BC--black cherry; WA--white ash; HIC--hickories; RM--red maple; Elm--elms; BG--blackgum; DW--dogwood; Misc. Hdws.--miscellaneous hardwoods including other trees plus shrubby species.

Dominance and Height Growth

Dominance based on tree height is probably ie best key to future stand development because rees in superior positions are most likely to mpete successfully for nutrients, water, and ght.

Dominance information is supplied on a rela- ve basis by calculating the percentage of the tal dominant stems that was composed of the me species or species group (table 4). At age oaks, yellow-poplar, red maple, black cherry, d white ash comprised 76 percent of the dominant ems on unburned area 3. On the burned areas, e above species increased in relation to elasped me since burning. On area 4, two years since rning; area 2, three years since burning; and ea 1, four years since burning; their respective mbined relative dominance is 46, 59, and 77 rcent. As time since burning increases and rubs and small tree species are relegated to the understory, the dominance of this group of species on areas 2 and 4 should increase. But as stand age increases further, we expect a decrease in the vigor of black cherry, white ash, and red maple. If this is true, then yellow-poplar will be the greatest competitor against oaks for space in the ultimate overstory. The effect of burning on the dominance of oaks over yellow-poplar is mixed. Oaks and yellow-poplar are nearly equal on area 4, very similar to unburned area 3. But on area 1, yellow-poplar is much more dominant and on area 2 the reverse is true. Differences in site quality, fire intensity, and stand age at time of burning may account for much of the variability.

Growth since burning has been exceptional on all areas. Average heights of dominant stems in area 1 four years after burning are almost equal to the 9-year-old unburned stand (table 4). However, many stems were not killed, so some dominant stems in area 1 were also 9 year old. On area 4 where all stems were topkilled, the 2-year-old

Table 4.--Relative dominance (RD) and average height in feet of the tallest woody stems on 3 burned and 1 unburned regeneration stands of upland hardwood on the southern Cumberland Plateau, Bankhead National Forest, Alabama (Fall 1979)[1]

Species	Area 3[2] Unburned		Area 1 Burned Spring 1976		Area 2 Burned Fall 1976		Area 4 Burned Spring 1978	
	RD	Avg. Ht.	RD	Avg. Ht.	RD	Avg. Ht.	RD	Avg. Ht.
	%	Ft.	%	Ft.	%	Ft.	%	Ft.
Oaks	19	25	9	22	18	16	10	9
Yellow-poplar	24	28	30	23	5	15	12	11
Red Maple	14	25	7	24	12	15	9	9
Black Cherry	13	28	15	25	15	20	11	10
White Ash	6	24	16	18	9	16	4	9
Dogwood	6	19	8	16	5	16	4	9
Blackgum	3	19	3	18	8	13	6	8
E. Hophornbean	0	--	0	--	1	10	18	9
E. Redbud	7	21	2	17	4	12	2	8
Sweetgum	0	--	1	26	8	20	1	11
Sassafras	0	--	3	17	0	--	4	10
Sumac	0	--	1	14	5	11	1	10
Others	8	--	5	--	10	--	18	--
Total	100		100		100		100	

[1] Dominance was determined by the tallest stem present on systematically located 10 m^2 (109 $ft.^2$) plots. Relative dominance =

$$\frac{\text{Number of plots on which a certain species is tallest}}{\text{Total number of plots}} \times 100$$

[2] Areas 3, 1, and 2 were harvested in fall 1970, site prepared in fall 1971; area 4 was harvested fall 1973, site prepared fall 1975.

dominant stems of major tree species average 3.1 m (10 ft.) in height.

Herbaceous Coverage

Herbaceous species or genera plus woody vines and Rubus spp. were grouped into various categories based on importance to wildlife (table 5). The value of prescribed burning to wildlife is apparent when total coverage between areas is compared. Herbaceous cover decreases as time since the fire increases, from 48.4 percent on a 2-year-old burn to 24.2 percent on a 4-year-old burn, and is lowest at 10.0 percent on the unburned 9-year-old stand.

Legumes, an important source of food for some game species, were scarce on all areas except areas 2 and 4. Wildlife food grasses and sedges, primarily Panicum spp. and Carex spp., were relatively abundant on the most recently burned areas, 2 and 4. Panicum grasses are heavily used by both game and nongame species in the southern United States. Rubus spp., blackberry and dewberry, another heavily used genera were abundant only on area 4. Vine coverage on the burned areas was double that of the unburned area. The vine category contains many species favored by white-tailed deer. The most abundant was poison-ivy but Alabama supplejack, green brier, and grape were also abundant. Only traces of forbs of high value to bobwhite quail were present.

DISCUSSION AND SUMMARY

This study was undertaken to supply information on the effects of fire on young stands of upland hardwoods. A primary interest was to determine if a single fire would increase the importance of oak in young stands. The 4 study areas observed had supported good quality stands --predominately oak--prior to clearcutting. Following clearcutting, some oak was obviously being replaced by faster growing species. The 9--year-old unburned stand (area 3) is indicative of how upland hardwood stands on good sites in the southern Appalachian plateaus will develop following clearcutting. The dominant stand contains yellow-poplar, oak, red maple, black cherry, eastern redbud, white ash, and flowering dogwood in that order. The original oak stand has been converted into a mixed stand where oak is still important but not predominant.

One fire in these young hardwood stands did not appreciably reverse the loss of oak or change

Table 5.--Percent coverage by herbaceous vegetation on burned and unburned regeneration areas of upland hardwoods on the southern Cumberland Plateau, Bankhead National Forest, Alabama (fall 1979)

Vegetative Category	Area 1[1] Burned Spring 1976	Area 2 Burned Fall 1976	Area 4 Burned Spring 1978	Area 3 Not Burned
	- - - - -	- - - - - Percent	- - - - -	- - - - -
Legumes	T[4]	3.4	2.0	T
Wildlife Food Grasses & Sedges	3.0	12.6	9.8	1.0
Other Grasses	T	2.4	2.4	T
Vines[2]	14.6	10.6	13.5	6.2
Rubus spp.[3]	2.0	1.6	19.0	T
Composites	2.0	2.4	1.0	1.0
Quail Food Forbs	T	T	T	T
Other Forbs	2.1	1.3	1.0	1.0
Total Coverage	24.1	34.4	48.4	10.0

1/ Areas 1, 2, and 3 were harvested in fall 1970 and site prepared in fall 1971; area 4 was harvested in fall 1973 and site prepared in fall 1975.

2/ Also includes woody vines.

3/ Blackberry and dewberry.

4/ T = trace (less than 1 percent).

ecies composition. However, the fires had
rge short term effects on stem density and
and structure, a favorable impact on wildlife
bitat, and some effect on species composition.
nsity of stems less than 1.4 m in height in-
eased substantially after burning because of
ltiple sprouting from topkilled stems. On area
burned 4 years earlier, density per 0.4 ha is
w 24,198 as compared with 7,790 before burning.
nsity of stems taller than 1.4 m was reduced
e first year after burning. However, because
rapid sprout growth, density 2 years after
rning approached or surpassed pre-burning
nsity on all 3 burned areas.

Some changes in species composition occurred
cause some stems were only topkilled and sprout-
while other stems were completely killed. The
t fire in the 4-year-old stand on area 4 com-
etely killed a number of small yellow-poplar
ems. Most of the stems killed were 1- and 2-
ar-old seedlings that had not developed a large
ot system. Although many small yellow-poplar
ems were killed, most of the larger stems;
eater than 1.4 m in height; sprouted, grew
pidly, and maintained their relative importance
the stand. Since yellow-poplar is a major
mpetitor against oak on good sites, burning
ung stands at the proper age and interval to
ntrol yellow-poplar may increase dominance of
k in the ultimate stand.

Red maple was the species that responded most
vorably to fire. Small-stem density increased
eatly on all burned areas. Although large-stem density increased on all areas, the relative increase was large, from 1.8 to 12.1 percent, only on area 1 which burned with a cool fire. Red maple is a major component of all 4 stands with moderately high density and dominance.

Although a single burning did not seem to greatly favor the development of oak, there were other positive wildlife benefits. The amount of browse available to white-tailed deer was greatly increased, and the increase was persistent 4 years after burning. Burning increased herbaceous growth that contained many important wildlife food plants. Herbaceous coverage ranged from 48.4 percent on a 2-year-old burn to only 10.0 percent on the unburned 9-year-old stand.

Since species composition was only slightly affected, the greatest negative impact of fire would be loss of growth and possible lowering of stem quality. The loss in growth was not as great as anticipated because of rapid sprout growth after burning. Average annual growth of the tallest stems of the major tree species was 1.5 m (4.8 ft.) in the 2-year-old burned area and 0.9 m (2.9 ft.) in the 9-year-old unburned area.

The damaging effect of fire upon hardwood stem quality is well known, and fire scars often serve as entry points for wood decaying organisms (Hepting 1935, Toole 1960). But the damaging effect on young stems that are topkilled may be small. Roth and Sleeth (1939) in a study of oak stands in the Allegheny, Appalachian, and central states found that sprout stands following severe burns had a lower decay incident than those resulting from cutting operations without fire. The plots with the lowest decay had been burned either shortly before or after cutting. They believed that fire reduced decay by lowering the origin of sprouts to or below ground level. Smith (1979) and Watt (1979) also concluded that decay should not be a significant problem in sprout origin reproduction. On area 1 where many stems were not topkilled, fire scaring is quite evident, although many of the smaller wounds have healed with callus growth. Jensen (1969) presents evidence that supports the hypothesis that a wound must remain open to maintain active decay. Shigo (1979) explains how trees, by the process of compartmentalization, restrict to small areas the defects that occur after wounding. Fire may also lower quality by increasing the incidence of multistemmed trees.

In summary, several conclusions can be drawn from our data. An oak component will be present in the developing stands but will be less than that in the original stands. On good sites yellow-poplar will be more abundant in the new stands than in the original ones. A single prescribed burn has a large initial effect on stand density and structure although long term effects appear small. Changes in species composition after burning are small, and oak is not apparently favored to any great extent. At this time many species are present in sufficient density to dominate the ultimate stand. At what age and size the various species will lose vigor and become less important in the stand can be determined only in time. Various wildlife species are benefitted by burning due to the increase in woody and herbaceous growth. The greatest detrimental impacts of burning are loss of growth and possible lowering of stand quality. When stands are burned at a young age and complete topkill occurs, the loss of growth and quality will be minimal.

LITERATURE CITED

Blair, Robert M., Henry L. Short, Leonard F. Burkart, Austin Harrell, and James B. Whelan.
1980. Seasonality and nutrient quality and digestibility of three southern deer browse species. U. S. Dep. Agric. For. Serv. Res. Pap. SO-161, 13 p. U. S. Dep. Agric. For. Serv., South. For. Exp. Stn., New Orleans, La.

Garren, Kenneth H.
1943. Effects of fire on vegetation of the southeastern United States. Bot. Rev. 9: 617-654.

Hamilton, W. J., Jr.
1941. The food of small forest mammals in eastern United States. J. Mammal. 22: 250-263.

Hepting, George H.
1935. Decay following fire in young Mississippi delta hardwoods. U. S. Dep. Agric. Tech. Bull. 494, 32 p.

Jensen, Keith F.
1969. Oxygen and carbon dioxide concentration in sound and decaying red oak trees. For Sci. 15: 246-251.

Little, S. and E. B. Moore.
1949. The ecological role of prescribed burns in the pine-oak forest of southern New Jersey. Ecology 30: 223-233.

McGee, Charles E.
1980. The effect of fire on species dominance in young upland hardwoods. In Proceedings of the Mid-South Upland Hardwood Symposium. (In Press).

McGee, Charles E.
1979. Fire and other factors related to oak regeneration. In Proc.: 1979 John S. Wright Forestry Conf. Regenerating Oaks in Upland Hardwood Forests, p. 75-81. Purdue Univ., West Lafayette, Ind.

McGee, Charles E. and Ralph M. Hooper.
1970. Regeneration after clearcutting in the southern Appalachians. U. S. Dep. Agric. For. Serv., Res. Pap. SE-70, 12 p. U. S. Dep. Agri For. Serv., Southeast. For. Exp. Stn., Ashevill NC.

McGee, Charles E. and Ralph M. Hooper.
1975. Regeneration trends 10 years after clearcutting of an Appalachian hardwood stand. U. S. Dep. Agric. For. Serv., Res. Note SE-227, 3 p. U. S. Dep. Agric. For. Serv., Southeast. For. Exp. Stn., Asheville, NC.

McLintock, Thomas F.
1979. Research priorities for eastern hardwoods Hardwood Research Council, Asheville, NC. 70 p

Martin, Alexander C., Herbert S. Zim, and Arnold L. Nelson.
1951. American wildlife and plants: A guide to wildlife food habits. Dover Publications, Inc., New York. 500 p.

Merritt, Clair.
1979. An overview of oak regeneration problems. In Proc.: 1979 John S. Wright Forestry Conf. Regenerating Oaks in Upland Hardwood Forests, p. 11-17. Purdue Univ., West Lafayette, Ind.

Merz, Robert W. and Stephen G. Boyce.
1958. Reproduction of upland hardwoods in southeastern Ohio. U. S. Dep. Agric. For. Serv. Tech. Paper 155, 24 p.

Roach, Benjamin A. and Samuel F. Gingrich.
1968. Even-aged silviculture for upland central hardwoods. U. S. Dep. Agric., Agric. Handb. 355, 39 p.

Roth, Elmer R. and Bailey Sleeth.
1939. Butt rot in unburned sprout oak stands. U. S. Dep. Agric., Tech. Bull. 684, 42 p.

Sander, Ivan L.
1977. Manager's handbook for oak in the north central states. U. S. Dep. Agric. For. Serv., Gen. Tech. Rep. NC-37, 35 p. U. S. Dep. Agric For. Serv., North Central For. Exp. Stn., St. Paul, Minn.

Sander, Ivan L.
1979. Regenerating oaks with the shelterwood system. In Proc.: 1979 John S. Wright Forestry Conf. Regenerating Oaks in Upland

Hardwood Forests, p. 54-60. Purdue Univ., West Lafayette, Ind.

nigo, Alex L.
1979. Tree decay, an expanded concept. U. S. Dep. Agric., Agric. Inform. Bull. 419, 73 p.

mith, H. Clay
1979. Natural regeneration and intensive cultural practices in central Appalachian hardwood stands using clearcutting and selection cutting practices. In Proc.: 1979 John S. Wright Forestry Conf. Regenerating Oaks in Upland Hardwood Forests, p. 30-42. Purdue Univ., West Lafayette, Ind.

tephens, George R. and Paul E. Waggoner
1980. A half century of natural transition in mixed hardwood forests. Connecticut Agric. Exp. Stn. Bull. 783, 43 p.

oole, E. Richard
1960. Butt rot of southern hardwoods. U. S. Dep. Agric. For. Serv., For. Pest Leaflet 43, 4 p.

rimble, G. J., Jr.
1973. The regeneration of central Appalachian hardwoods with emphasis on the effects of site quality and harvesting practice. U. S. Dep. Agric. For. Serv. Res. Pap. NE-282, 14 p. U. S. Dep. Agric. For. Serv., Northeast. For. Exp. Stn., Broomall, Pa.

an Dersal, William R.
1940. Utilization of oaks by birds and mammals. J. Wildl. Manage. 4: 404-428.

att, Richard F.
1979. The need for adequate advance regeneration in oak stands. In Proc.: 1979 John S. Wright Forestry Conf. Regenerating Oaks in Upland Hardwood Forests, p. 11-17. Purdue Univ., West Lafayette, Ind.

APPENDIX I

Scientific and Common Name of Woody Species[1]

ientific Name	Common Name
cer rubrum L.	red maple
cer saccharum Marsh.	sugar maple
arya spp.	hickory
ercis canadensis L.	eastern redbud
ornus florida L.	flowering dogwood
ataegus spp.	hawthorn
agus grandifolia Ehrh.	American beech
axinus americana L.	white ash
drangea arborensens L.	smooth hydrangea
glans nigra L.	black walnut
riodendron tulipifera L.	yellow-poplar
gnolia acuminata L.	cucumbertree
ssa sylvatica Marsh.	blackgum
Ostrya virginiana (Mill.) K. Koch	eastern hophornbean
Prunus serotina Ehrh.	black cherry
Prunus spp.	plum
Quercus alba L.	white oak
Quercus coccinea Muenchh.	scarlet oak
Quercus falcata Michx.	southern red oak
Quercus prinus L.	chestnut oak
Quercus rubra L.	northern red oak
Quercus velutina L.	black oak
Rhamnus caroliniana Walt.	Carolina buckthorn
Rhododendron nudiflorum (L.) Torr.	pink azalea
Rhus spp.	sumac
Ulmus spp.	elm

Herbaceous and Vine Species

Berchemia scandens (Hill) K. Koch	Alabama supple-jack
Carex spp.	sedge, carex
Panicum spp.	panicum
Rhus radicans L.	poison ivy
Rubus spp.	blackberry and dewberry
Smilax spp.	greenbrier
Vitis spp.	grape
Zea mays L.	corn

APPENDIX II

Common and Scientific Names of Animal Species[2]

Common Name	Scientific Name
	Birds
Blue jay	Cyanocitta cristata
Bobwhite quail	Colinus virginianus
Brown thrasher	Toxostoma rufum
Common grackle	Quiscalus quiscula
Lesser prairie chicken	Tympanuchus pallidicinctus
Red-bellied woodpecker	Centurus carolinus
Red-headed woodpecker	Melanerpes erythrocephalus
Ruffed grouse	Bonasa umbellus
Rufous-sided towhee	Pipilo erythrophthalmus
Tuften titmouse	Parus bicolor
White-breasted nuthatch	Sitta carolinensis
Wild turkey	Meleagris gallopavo
Wood duck	Aix sponsa
	Mammals
Black bear	Ursus americanus

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[1] Names based on Little, Elbert L., Jr., 79, Checklist of United States Trees and rnald, M. L., 1950, Gray's Manual of Botany.

[2] Bird names according to Robbins, Chandler S., B. Bruun, H. S. Zin, and A. Singer, 1966, Birds of North America; and mammal names according to Burt, W. H. and R. P. Grossenheider, 1964, A Field Guide to the Mammals.

Deer mouse	Peromyscus maniculatus
Eastern chipmunk	Tamias striatus
Eastern gray squirrel	Sciurus carolinensis
Flying squirrel	Glaucomys volans Glaucomys sabrinus
Fox squirrel	Sciurus niger
Raccoon	Procyon lotor
Redback vole	Clethrionomys grapperi
White-footed mouse	Peromyscus leucopus
White-tailed deer	Odocoileus virginianus

PRESCRIBED FIRE ON SLOPING TERRAIN IN WEST TENNESSEE TO MAINTAIN LOBLOLLY PINE (PINUS TAEDA L.)[1]

Peter de Bruyn and Edward Buckner[2]

Abstract.--Prescribed burning in a 22-year-old loblolly pine plantation killed 40 percent of the understory hardwoods and reduced fuel levels approximately 43 percent. Soil pH increased following spring and summer burns, but decreased following the fall burn. Burning times in sampling transects ranged from 30 to 245 minutes, depending on burn type, slope percent, and wind speed.

INTRODUCTION

Tennessee is in a transition position between ne Central Hardwood Region, dominated by various ak-hickory associations, and the Southern Pine egion where the yellow pines are dominant. Most f Tennessee's commercial forestland is on upland ites, with oak-hickory the dominant cover type; ver 90 percent of the forest cover is hardwoods. ccording to the forest survey, however, pproximately one-half of the commercial forest-and in Tennessee will be most productive if anaged for pine (Wells, et al., 1974).

Over the last three decades forest indus-ries have converted thousands of acres of ennessee's upland hardwood forests to pine lantations. This trend continues and represents ne most intensive forestry currently being racticed in the state.

Attempts to convert hardwood stands to pine re hampered by the aggressive seeding and root-prouting of hardwoods. The intensive site reparation measures currently being used to ontrol unwanted hardwoods may alter soil proper-ies sufficiently to reduce productivity. Most f the older pine plantations in this region have ggressive hardwood understories that compete for oil moisture and nutrients and will make pine egeneration more difficult and expensive.

Greater industrial demand for pines and their greater productivity on most upland sites in this region make the natural progression from pines to hardwoods economically undesirable. Pines can be maintained only by repeated disturbances that discriminate against hardwoods. The greater susceptibility of hardwoods to fire damage provides the forest managers with an economical tool for maintaining pine on sites that would otherwise progress toward a hardwood climax (various oaks on most upland sites in Tennessee).

While a great deal is known about the behavior and effects of prescribed fire in the deep South, it has been little used in the rolling to steep terrains characteristic of most of Tennessee. Aggressive hardwood competition and high fuel levels in the pine plantations now common over much of Tennessee make prescribed fire an attractive management tool. Forest managers need safe and effective guidelines for its use in this region.

METHODS

The objectives of the study were to determine the effects of selected methods of prescribed burning on: 1) the hardwood understory, 2) nutrient mobility in the soil, 3) fuel levels, and 4) the growth rate of plantation pines. A 22-year-old loblolly pine (Pinus taeda L.) plantation in West Tennessee was selected for this study.

Treatment plots of approximately 3/4 hectare were located on the west and east sides of a north-south oriented ridge. Burns were conducted in each season except winter when burning was not possible due to adverse weather conditions. Each seasonal test consisted of 4 contiguous treatment plots, 2 on the west facing slope and 2 on the east. On each slope one burn originated from the ridge crest and the other from the base of the slope. Since desirable burning conditions for this region call for 3-8 km/h winds out of the west, this arrangement permitted evaluation of headfires burning both up and downslope and backfires burning both up and downslope.

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[1] Paper presented at Southern Silvicultural esearch Conference, Atlanta, Georgia, November -7, 1980.

[2] Graduate Student and Associate Professor Forestry, respectively, The University of ennessee, Knoxville, Tennessee 37901.

In each treatment plot the hardwood understory was sampled along 4 transects (3 meters wide by 50 meters long) oriented up and downslope. In each transect the hardwood understory was inventoried according to species and size class. Following burning each hardwood identified in the pre-burn inventory was assigned to one of the following classes: 1) killed, 2) killed back but sprouting, and 3) alive. All plantation pines within transect boundaries were measured and tagged prior to burning. Remeasuring took place during the dormant season over a 2-year period. Mortality of the croptrees was recorded at each reinventory.

Soil samples were collected prior to and after burning to determine the release of selected nutrients and the effect of burning on soil pH. Six sampling sites were chosen in each treatment plot, 2 on the upper-, 2 on mid-, and 2 on the lower-slope positions. At each sampling point three samples were collected representing the 0-10 cm, 11-20 cm, and 21-30 cm depths.

Forest floor samples were collected at 4 locations in each treatment plot prior to burning to determine the amount of fuel per hectare and its moisture content at burning time. The same sampling scheme was used after burning to determine the reduction in fuel per hectare due to burning.

During each burn relative humidity, ambient air temperature, and wind velocity and direction were monitored. The duration of each burn (time required for the fire to travel the length of the transects) was recorded. Thermocouples were buried beneath the forest floor, at its interface with the mineral soil, at 3 positions on the slope to determine the relative temperatures attained in the different burn types.

RESULTS

Weak and/or variable winds during burns prevented evaluation of headfires and backfires as originally planned. The time required for each fire to burn the 50 meter length of the sampling transect (rate of burn) was substituted as an integration of slope and windspeed effects in evaluating results.

Fuel reduction was not related to the rate of burn, but was greater when both fuel moisture and relative humidity were low. The greatest reduction in fuel levels resulted from the fall burn of 1978, an extremely dry fall for this region, where fuels were reduced 58 percent compared to approximately 40 percent for the other burns. Fuel reductions in treatment plots ranged from 20 to 70 percent.

Although highly variable,soil P increase averaged approximately 3 kg/ha following burning (Table 1). The increase was greatest at the 0-10 cm level, and was the smallest in the 11-20 cm level but increased again in the 21-30 cm level. These changes probably reflect soil textural differences with higher clay and organic matter contents associated with increased soil P. Soil K changes were highly variable and, as a percentage of that extracted in the soil test procedure, overall increases were much smaller than for P. Soil pH decreased mainly following the fall burn, while there was a slight increase in soil pH following summer and spring burns. Th may be associated with the extremely dry conditio and hot burns that fall.

Table 1.--Changes in soil phosphorus and potassium following burning (kg/ha).

	Depth(cm)	Preburn	Postburn	Change
PHOSPHORUS				
	0-10	5.8	9.9	+4.1
	11-20	5.3	5.7	0.4
	21-30	5.7	7.8	+2.1
POTASSIUM				
	0-10	111	117	+7
	11-20	137	148	+11
	21-30	182	185	+3

Species susceptibility to fire varied greatl (Table 2). While only 21 percent of the sassafra

Table 2. Species arranged according to decreasing susceptibility to fire.

SPECIES	MORTALITY PERCENT
eastern red cedar (Juniperus virginiana L.)	93
sugar maple (Acer saccharum Marsh.)	85
yellow poplar (Liriodendron tulipifera)	80
wild black cherry (Prunus serotina Ehrh.)	75
red maple (Acer rubrum L.)	61
dogwood (Cornus florida L.)	58
witch-hazel (Hamamelis virginiana L.)	54
vaccinium (Vaccinium spp.)	50
viburnum (Viburnum spp.)	50
red oak (Quercus spp.)	41

Table 2 (cont.)

SPECIES	MORTALITY PERCENT
white oak (*Quercus* spp.)	40
sweetgum (*Liquidambar styraciflua* L.)	34
ash (*Fraxinus* spp.)	28
elm (*Ulmus* spp.)	25
black gum (*Nyssa sylvatica* Marsh.)	23
hickory (*Carya* spp.)	22
sassafras (*Sassafras albidum* Nutt.)	21

ems were killed;93 percent of the eastern red dar stems were killed. Susceptibility to fire s not found to differ among seasons.

Fuel reduction and hardwood mortality were eatest in the fall 1978 burns when forest fuels re extremely dry. This relationship among fire tensity, fuel reduction, and hardwood mortality peared to hold for conditions prevailing in the ree seasons tested (Table 3). Relative humidity d fuel moisture appeared to interact to control re intensity.

ble 3.--Relationship between burning conditions and burn effects.

	BURNING CONDITION		BURN EFFECT	
BURN SEASON	RELATIVE HUMIDITY	FUEL MOISTURE CONTENT	FUEL REDUCTION	HARDWOOD MORTALITY
	PERCENT	PERCENT	PERCENT	PERCENT
mmer 1978	60	24	40	35
11 1978	35	24	58	44
ring 1979	30	42	42	41

The diameter growth of plantation pines was t related to any of the burn effects. However, optree mortality was related to fire intensity. fty-one croptrees died following the fall burn 1978 in which there was a 58 percent fuel duction, and 28 croptrees died following the mmer burn that year in which there was a 40 rcent fuel reduction.

Thermocouple readings varied greatly during e summer and fall burns; maximum temperatures the litter-mineral soil interface ranged from to 100+ degrees Centigrade. Fluctuations ring the spring burn 1979 were far less (48 to degrees Centigrade) due to a higher fuel moisre content.

DISCUSSION AND CONCLUSION

Restricting prescribed burning to periods of "optimum" fuel moisture and weather conditions is difficult if not impossible, especially when large acreages are involved. The small and highly variable differences found in this study among seasons, fire type, and rate of burn suggest that "fire is fire" and getting burning accomplished should be the primary concern rather than waiting for "optimum" conditions. Experience has shown that "optimum" burning conditions rarely occur due to the large number of uncontrollable variables, most of which are weather related.

In general, hardwood control and fuel reduction was best accomplished in the fall 1978 burns which were carried out when the fire danger rating was high. Since fire type had little effect, it appears that the primary objectives for using prescribed fire in the hilly terrain of Tennessee are best met by using fire types that are easily controlled (e.g., backfires downslope) when forest fuels are highly combustible.

LITERATURE CITED

Wells, G. R., A. Hedlund, and T. M. Earles. 1974. Assessment of Tennessee timberland: a guide to implementing the productivity approach. U.T. Ag. Exp. Sta. Bull. 527.

LOW INTENSITY BURN PRIOR TO BEDDING AND PLANTING SLASH PINE IS OF LITTLE VALUE[1]

Dale D. Wade and Lawrence P. Wilhite[2]

Abstract.--On a Lower Coastal Plain site in Georgia, unburned plots and plots that had received a low-intensity broadcast burn were drum chopped, bedded, and machine planted to slash pine *(Pinus elliottii* Engelm. var. *elliottii)*. Measurements through 6 years after planting suggested that burning had little or no effect on survival, fusiform rust infection, overtopping, or growth of pine seedlings. Independent of the effects of burning, pine growth was significantly reduced by early, transitory overtopping and by proximity to bluestem grasses or bitter gallberry.

INTRODUCTION

For many decades, foresters have burned clearcut southern pine sites to prepare them for pine planting. These prescribed fires reduced the wildfire hazard, facilitated planting, and increased survival and growth of the pine seedlings. During the last few decades, even better performance of pines has been achieved by following the burn with various types and intensities of mechanical site preparation. We question the benefits of such burning when conditions preclude a hot fire and when the area is also scheduled for intensive mechanical treatment.

The study described here was designed to measure the benefits, if any, of a light intensity fire prior to bedding to prepare a site for planting of slash pines *(Pinus elliottii* Engelm. var. *elliottii)*. Observations on the effects of competing vegetation on seedling growth are also reported.

The study area is on the Lower Coastal Plain in Echols County, Georgia, on land leased by St. Regis Paper Company of Jacksonville, Florida. Soil is a poorly drained Leon fine sand. A natural stand of slash pine was harvested from the area 6 years before it was site prepared.

Observations and measurements taken on thirty 1/4-milacre plots just prior to preparation revealed that the vegetative cover of the site consisted mostly of bitter gallberry, bluestem grasses, saw palmetto, blueberry bushes, fetter bushes, and threeawn and dropseed grasses.[3] The ovendry weight of vegetation, or standing fuel, was estimated to be 4.1 tons per acre.

During the 6 years between clearcutting and site preparation, most of the logging debris, and all of the pine-needle litter, had decomposed. The litter layer, therefore, was composed mostly of fallen leaves from shrubs and dead herbaceous material. It was estimated to weigh less than 1/2 ton per acre.

METHODS

Site Preparation and Planting

St. Regis scheduled the site for broadcast burning in August 1971, to be followed by scarification with an offset, tandem-drum chopper and the raising of 6-inch-high beds on 12-foot centers with a bedder-packer. After allowing several weeks for soil settling, 1-year-old nursery seedlings of slash pine were to be planted 6 feet apart along the beds with a Lowther drag-type planting machine in which a planter rides facing forward and inserts seedlings into the planting slit.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

[2] Authors are Research Foresters, USDA Forest Service, Southeastern Forest Experiment Station, Southern Forest Fire Laboratory, Macon, Georgia 31202, and Forestry Sciences Laboratory, Charleston, South Carolina 29407, respectively.

[3] Scientific names of competing plants are provided in table 1.

To accomodate our study, four 1/2-acre blocks ere established on the study site before burning, nd half of each block was randomly chosen to emain as an unburned but chopped and bedded plot.

Firelines were plowed in August 1971 to proect four 1/4-acre plots from the broadcast burn hat would be set as soon as conditions were favorble. The next several months, however, illustraed one of the problems that prompted us to estabish this study: rain began falling whenever uel moisture conditions indicated that the site ould soon be dry enough to burn.

The area finally dried out enough to carry fire in early November. The ensuing fire raversed between 60 and 81 percent of the four urned plots, topkilling the grasses, forbs, and maller shrubs. We estimated fire intensity to e less than 50 BTU's per second per foot of fire ine. All unburned portions of the burned plots ere mapped so that after planting these portions ould be excluded from the 100-tree measurement lots. The entire study area was chopped in anuary, bedded in February, and planted in arch of 1972.

easurements

After planting, the distances between plantg positions were measured to determine if burng facilitated construction of beds and thus ermitted more uniform planting spacing. Also, ach measurement seedling was judged to be either ell planted, deep planted, shallow planted, or planted (released from the planting machine at e proper distance, but not actually planted).

Seedling heights and diameters and incidence cankers (caused by *Cronartium fusiforme* Hedgc. Hunt) were recorded periodically through 6 years ter planting.

Changes in understory fuel weight and underory plant species were documented on two 1/4-lacre plots located in each treatment plot. rcent crown cover of the various understory ecies was estimated using a light table, a dot id, and stereo-pairs of 35-mm color transparenes. These transparencies had been taken downward om a portable camera support over permanent adrats as described by Pierce and Eddleman (1970).

Competition to the pines, including overtopng, was periodically evaluated by recording the ecies of plant within 1 foot of each surviving asurement pine that appeared to be offering the st competition to that pine.

atistical Analyses

Analyses of variance for a completely randomed design were used to compare differences beeen the burned and unburned treatments. Factors examined included quality of planting; height, diameter and survival of the pines; incidence of fusiform cankers; percent of pines overtopped by competing vegetation; weight of understory fuels; and frequencies of various understory species.

Data from the burned and unburned plots were combined for analysis of effects of overtopping species on height and diameter of pines. Again, differences were evaluated by analysis of variance.

Differences between percent crown coverage of burned and unburned understories were analyzed by a t-test.

RESULTS AND DISCUSSION

Seedling Performance

Seedling spacing along the planting rows averaged 5-1/2 feet for both the burned and unburned plots, but the standard deviation in spacing was actually greater for the burned plots. Burned plots contained more well planted seedlings than the unburned plots (92 versus 88 percent), but the difference was not statistically significant. Thus, burning before mechanical preparation resulted in little, if any, improvement in planting.

A comparison based upon all measurement positions 6 years after planting showed the following:

	Burned plots	Unburned plots	Significant level of difference
6th Year:			
percent survival	89	83	NS
height in feet	15.6	16.6	NS
DBH in inches	2.65	2.85	NS

These differences are not sufficient to judge one treatment better than the other.

By 6 years after planting, 5 trees on the unburned plots had been killed by fusiform rust cankers and 18 survivors had stem cankers, whereas no trees had been killed by fusiform on the burned plots and 16 survivors had stem cankers. The differences, however, were not statistically significant.

Understory Development

Immediately after chopping and bedding, both the burned and unburned plots were essentially devoid of standing vegetation. Recovery of vegetation appeared to be faster on the unburned plots, but differences between treatments in height and density of competing vegetation and in numbers of pines overtopped were not statistically significant.

Bitter gallberry bushes and bluestem grasses dominated the understory before preparation. They still dominated it after preparation (table 1). Saw palmetto, blueberry bushes, fetter bushes, and threeawn and dropseed grasses were less prevalent after site preparation than before. The other species listed in table 1 were encountered too infrequently to judge the effect of site preparation upon their numbers. In general, however, the understory on both the burned and unburned plots three years after preparation looked much as it had before preparation.

No significant differences between burned and unburned plots were found in the frequencies of bitter gallberry, or bluestem grasses, or threeawn plus dropseed grasses or panic plus paspalum grasses. Frequencies of the other species listed in table 1 could not be statistically compared because they were absent from one or more plots.

Woody plant competition to pines on the burned plots, initially low, increased to almost that on the unburned plots by 6 years after planting (fig. 1). At no measurement, however, was the difference significant.

Table 1.--Species within 1 foot of the surviving pines that appeared to be offering the most competition to individual pines, expressed as percentages of planting positions with surviving pines.1/

Species or Species Groups	One year after planting		Three years after planting		Six years after planting	
	Burned	Unburned	Burned	Unburned	Burned	Unburned
			- - - - - - - - - - - - percentages	- - - - - - - - - - - -		
WOODY PLANTS						
Bitter gallberry *(Ilex glabra* (L) Gray*)*	24.3	28.7	53.0	56.3	72.4	71.8
Southern waxmyrtle *(Myrica cerifera* L. var. *cerifera)*	0.3	1.4	0.9	2.0	2.9	4.8
Fetter bushes *(Lyonia* spp. Nuttall*)*	1.5	1.3	1.4	1.4	0.7	0.0
Redbay *(Persea borbonia* (L) Sprengel*)*	0.3	0.5	0.6	1.0	0.6	2.4
Sweet pepperbush *(Clethra alnifolia* L.*)*	2.8	2.1	0.3	0.3	0.3	0.0
Chokeberry *(Sorbus arbutifolia* (L) Heynhold*)*	0.9	4.9	0.0	1.3	0.0	0.0
Saw palmetto *(Serenoa repens* (Bartram) Small*)*	0.4	0.8	1.5	2.1	0.6	1.5
Sweet gallberry *(Ilex coriacea* (Pursh) Chapman*)*	0.0	0.3	0.0	1.0	0.0	0.0
Blueberries *(Vaccinium* spp. L.*)*	3.1	5.9	0.6	0.0	0.0	0.0
Red maple *(Acer rubrum* L.*)*	0.3	0.0	0.3	0.0	0.3	0.4
Grape *(Vitis* spp. L.*)*	0.0	0.0	0.0	0.0	0.0	0.3
Greenbrier *(Smilax* spp. L.*)*	0.5	0.0	0.0	0.0	0.0	0.0
HERBACEOUS PLANTS						
Bluestem grasses *(Andropogon* spp. L.*)*	17.0	26.4	38.4	33.1	22.2	18.9
Threeawn and dropseed grasses *(Aristida* spp. L. and *Sporobolus* spp. R. Brown*)*	5.6	3.1	0.3	0.3	0.0	0.0
Panic and paspalum grasses *(Panicum* spp. L. and *Paspalum* spp. L.*)*	29.2	10.2	0.0	0.0	0.0	0.0
Other grasses and grasslikes (Poaceae, Cyperaceae, and Juncaceae)	8.8	7.1	2.6	1.2	0.0	0.0
Composites (Asteraceae)	3.3	1.6	0.0	0.0	0.0	0.0
Redroot *(Lachnanthes caroliniana* (Lam.) Dandy*)*	0.3	2.3	0.0	0.0	0.0	0.0
Ferns	0.0	0.7	0.0	0.0	0.0	0.0
Unidentified Herbaceous species	0.8	1.4	0.0	0.0	0.0	0.0
NO COMPETING PLANTS WITHIN 1 FOOT OF PINES	0.6	1.3	0.0	0.0	0.0	0.0
TOTAL PERCENT	100.0	100.0	99.9	100.0	100.0	100.1

1/For example, the first numerical entry indicates that 24.3 percent of the pines surviving on the burned plots 1 year after planting appeared to be receiving more competition from bitter gallberry than from any other species.

The measurement of crown coverage using ertical stereophotographs indicates that vegeta-ive recolonization of the study site was rapid, ith more than 90 percent of the site covered ith vegetation 2 years after site preparation. ercent cover of herbs peaked at 2 years, then ecreased during the next year as coverage of oody plants increased. Neither the woody nor ne herbaceous coverage differed significantly etween the burned and unburned plots. Graphic resentation of this coverage (fig. 2) suggests, owever, as did the competition data in figure 1, nat burning plus mechanical preparation resulted n more effective initial control of woody plants nan did mechanical preparation alone.

Of the 436 well-planted pines not overtopped other vegetation 1 year after planting, only subsequently became overtopped (temporarily), d only 6 died between the first and sixth years fter planting. Of the 158 well-planted pines vertopped at 1 year, only 3 were still over-opped at 3 years, 2 were overtopped at 4 years, was overtopped at 6 years, and only 2 died etween the first and sixth years. Despite its ansitory nature, the overtopping, or something ssociated with it, reduced height and diameter owth through 6 years after planting:

Years since anting	Pines overtopped at 1 year	Pines not overtopped at 1 year	Significant level of difference
	- - - - - - height in feet - - - - - -		
0	0.7	0.7	NS
1	1.0	1.1	0.005
4	8.0	9.0	0.005
6	15.0	16.6	0.05
	- - - - - - DBH in inches - - - - - -		
6	2.50	2.85	0.05

The most meaningful of the competition measure-nts appeared to be the one made 6 years after anting among the well-planted surviving pines at were not infected with stem canker. In that asurement, 73 percent of the pines were judged be receiving their major competition from tter gallberry, 19 percent from bluestem grasses, d the remaining 8 percent from saw palmetto, tter bush, waxmyrtle, redbay, red maple, or ape vine. Average height and diameter of the nes varied with the species of the competitor:

Competitor	Pine Height	Pine DBH
	feet	inches
Bluestems	15.3	2.6
Gallberry	16.4	2.8
All others	17.3	3.1

Pines competing with the bluestems (chiefly *Andropogon virginicus* L. and *A. capillipes* Nash) averaged significantly shorter (0.05 level) and smaller in diameter (0.025 level) than pines competing with those species referred to collectively as "all others". The growth retarding effect of the bluestems upon slash pine may be less of a competition effect than an allelopathic effect, considering that Priester and Pennington (1978) found that water extracts from the shoots of *A. virginicus* slowed the height growth of loblolly pine *(Pinus taeda* L.*)* seedlings.

Pines competing with bitter gallberry were significantly smaller in diameter (0.025 level) but not significantly shorter than pines competing with the "all others" category. Pines competing with bitter gallberry did not differ significantly in height or diameter from pines competing with bluestems.

SUMMARY AND CONCLUSIONS

Growth of slash pine seedlings was signficantly reduced by proximity to bluestem grasses or to bitter gallberry, or by temporary overtopping by any competing plants. This information may be of more direct use to the forester researcher than to the forest manager.

Of more immediate use to the forest manager are the results indicating that prescribed fire before mechanical preparation may not be necessary. Effects of the low intensity fire before chopping, bedding, and planting had neither practical nor statistical significance. A fire of higher intensity might have produced differences of statistical and economic significance. The fact remains, however, that without any prescarification fire, slash pine averaged 16 feet tall and 83 percent survival 6 years after planting. Under the conditions of the study, an entirely adequate plantation was established without burning!

Because most of the logging debris had decomposed and the mechanical treatments had adequately controlled the competition, burning was not cost effective. Prescarification burning probably is equally unnecessary on sites where most of the combustible material has been removed by whole-tree harvesting. Even on sites with more debris, a prolonged wait for good burning conditions could result in the cost of burning outweighing its benefits. If such a wait seems likely, and a mechanical treatment that will allow acceptable stand establishment at an acceptable cost is available, burning should probably be foregone.

LITERATURE CITED

Pierce, William R., and Lee E. Eddleman.
1970. A field stereophotographic technique for range vegetation analysis. J. Range Manage. 23:218-220.

Priester, David S., and M. T. Pennington.
1978. Inhibitory effects of broomsedge extracts on the growth of young loblolly pine seedlings. USDA For. Serv. Research Paper SE-182, 7 p. Southeast. For. Exp. Stn., Asheville, N. C.

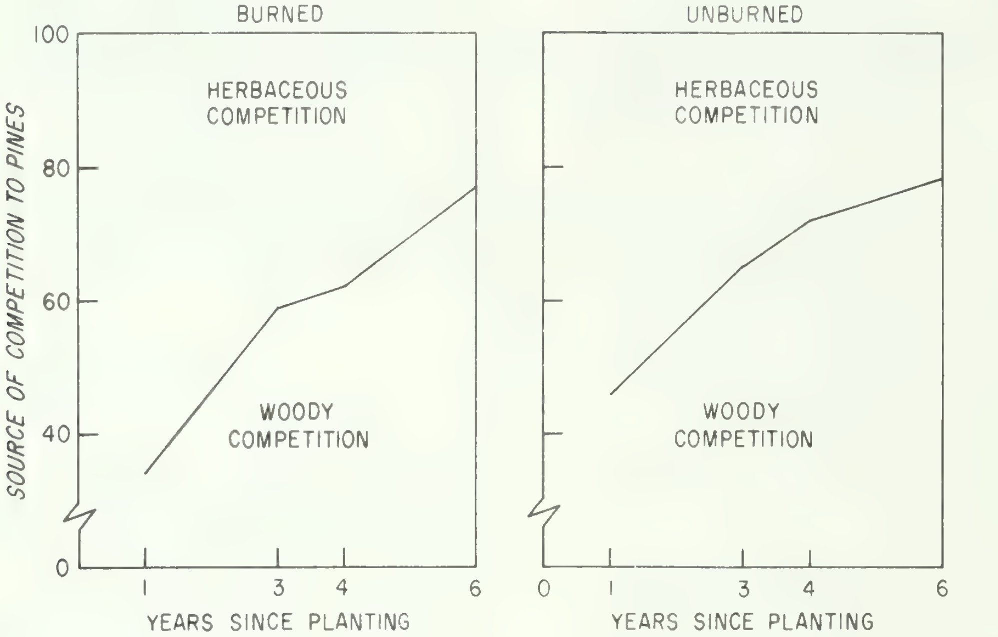

Figure 1.--Trend toward woody competition with time since site preparation.

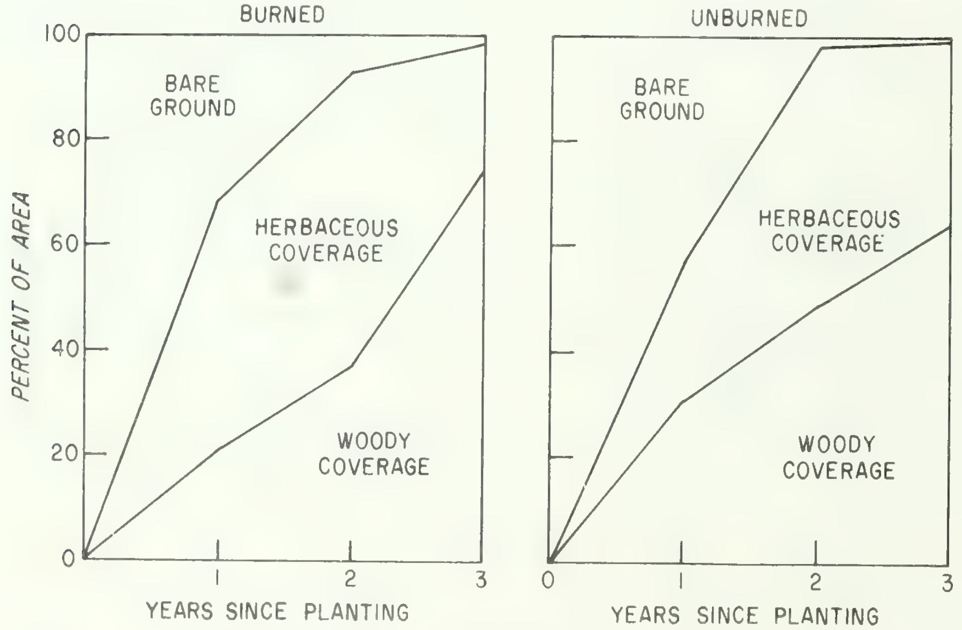

Figure 2.--Trend toward woody understory coverage with time since site preparation.

BOTTOMLAND HARDWOODS RESEARCH ON SITE PREPARATION, PLANTATION ESTABLISHMENT, AND CULTURAL TREATMENTS, AT THE SOUTHERN HARDWOODS LABORATORY[1]

Harvey E. Kennedy, Jr.[2]

Abstract.--The South contains about 219 million acres of forests, 70 million acres of which are most productive when managed as hardwoods. Bottomland hardwoods cover about 22 million of this 70 million acres. Hardwood plantation management has been increasing during the last few years, but natural stand management still accounts for more than 99 percent of hardwood production in the South. This paper summarizes research and experience at the Southern Hardwoods Laboratory that have solved some of the problems in plantation management. Proper site selection, good site preparation and cultivation, high quality seedlings, and proper planting techniques are musts if hardwood plantations are to be successful. Planting large seedlings may reduce costs of site preparation and cultivation, as well as get more desirable seedlings into an area.

The South contains more than 532 million cres of land. Forests cover 41 percent of this and area. Of the 219 million acres of forest and, 70 million acres are most productive when anaged for hardwoods. Bottomland hardwoods otal 22 million acres, with upland and mountain ardwoods comprising the remaining 48 million cres. In 1977, 54 percent of the hardwoods harested in the eastern United States came from the outh.

Hardwoods were the primary object of eariest forest management practices in the United tates, but the emphasis shifted rapidly to coniers that were demanded by industry and more asily managed. High-grading, fire, grazing, and oor markets for intermediate products have aused hardwoods to be neglected in forest manageent.

Recently, the demand for hardwood products such as furniture, pallets, pulpwood, construction material, and fuelwood has increased. To meet the higher demand for hardwood products, better forest and plantation management with supplemental planting of desired species in natural stands will have to be practiced.

This paper summarizes some research results on plantation establishment, site preparation, and cultural treatments at the Southern Hardwoods Laboratory.

SITE PREPARATION AND CULTIVATION

One of the first prerequisites for successful hardwood plantations is proper site selection. Species must be adapted to the site. The most desirable sites would be moist but well-drained sandy loams and silt loams in most southern river bottoms. Best growth for all species occurs at sites receiving ample moisture during the growing season (McKnight 1970). Many hardwoods can withstand flooding during the dormant season if the water is cool and moving or does not stay on the ground for extended periods during the growing season. Our experience has shown that flooding during the first growing season can be very damaging to young hardwood plantations, but trees can withstand prolonged flooding after the first growing season.

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[1] Paper presented at Southern Silviultural Research Conference, Atlanta, Georgia, ovember 6-7, 1980.

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Sites which are recommended for planting are inherently fertile, and the climate in the South is well suited for excellent growth. Weeds as well as trees grow rapidly, but most hardwoods are intolerant and can stand little if any competition for light and moisture when trees are young. Careful site preparation is essential to get trees established and to make weed control easier during the first growing season (McKnight 1970).

Site preparation is the most costly phase in establishing southern bottomland hardwood plantations. In 1976, contract clearing, raking, windrowing, burning, and disking costs were about $150 per acre (Johnson 1977). This cost may be as much as $200 or more per acre now. Such intensive site preparation is required to do the straddle cultivation essential to achieve nearly complete control of vines, weeds, sprouts, and other seedlings while planted seedlings are being started. Also added to the clearing costs would be $50-60 per acre for first-year cultivation. The plantation needs to be cultivated at 3- to 4-week intervals five to six times the first growing season. Clearing costs under contract programs may be bettered by companies using their own equipment.

Best sites for most hardwoods are on land recently cleared of timber. The soil is in good physical condition and weeds are usually not plentiful (McKnight 1970). Trees should be sheared and the site thoroughly cleaned and disked to facilitate planting and first-year cultivation. Stumps left after logging and standing unmerchantable trees and shrubs should be cut at or just below the groundline. The sheared material should be windrowed and burned. Some of the debris from near the edge of the clearing operation can be used to construct crude fences to exclude deer if they are a problem. These fences need to be 10 to 12 feet in height and about 20 feet across the base.

Use of "old-field sites" will eliminate the cost of clearing. Experience and research have shown, however, that these sites need to be deep plowed (fallowed) before planting. Plowing breaks the sod, reduces competition from weeds, eliminates compaction, aerates the soil, and allows rapid infiltration of moisture from rainfall. Baker and Blackmon (1978) reported on summer fallowing as a simple technique for improving old-field sites for cottonwood. This technique should also work for other hardwoods.

For cultivation, most forest managers prefer tractors of about 100 horsepower, a size large enough for clearing, fallowing, and planting, but small enough for cultivating (Kennedy and Henderson 1976). One tractor per 200 acres is required for adequate results. Commercial planters are straddle cultivating one row at a time with conventional front-mounted farm cultivators until trees are about 2 feet tall. Front-mounted cultivators allow the driver to have better visibility and control and therefore cause less damage to trees than with rear-mounted cultivators. Cultivators equipped with chisel- or shovel-type plows allow tillage close to young trees without appreciable damage. Equipment most frequently used consists of: (1) large front-mounted cultivators with 19 to 21 shanks that will straddle one row while covering the space within rows, or (2) offset front-mounted cultivators equipped with 5 to 6 shanks that straddle the row while covering a small area on each side; with this system, a disk or spring-tooth harrow drawn behind the tractor covers the area between rows. When trees are too tall to straddle, the cultivators are removed, and tillage between rows is accomplished with a disk or harrow.

PLANTATION ESTABLISHMENT

In the past few years plantation acreages have been increasing and today there are between 100,000 and 150,000 acres (Johnson 1977). However, in the eastern United States, natural stands still account for over 99 percent of the hardwood production.

Research and experience have solved many of the problems of growing cottonwood and other hardwoods in plantations (Johnson 1977). Species being grown in plantations today are cottonwood, sycamore, sweetgum, green ash, and black walnut.

After site preparation, the area is ready for planting. The planting operation can be accomplished by hand with dibbles or with machines, whether planting hardwood seedlings or cottonwood cuttings. Good planting techniques and quality seedlings are a must if the plantation is to be a success. Forest owners are now looking for quality seedlings with a rootcollar diameter at least 1/4- to 3/8-inch or larger and tops 30 to 36 inches tall (McKnight and Johnson 1980, Weber 1972). Cottonwood cuttings should be 3/4- to 1-inch at the large end and a minimum of 3/8-inch at the small end.

High site preparation cost is probably the main deterrent of hardwood plantation establishment at this time. Ongoing research at the Southern Hardwoods Laboratory is aimed at overcoming the expensive site preparation and cultivation costs by planting large seedlings. Work is currently underway with cottonwood, sycamore, and four oaks. The objective is to improve early height growth by planting trees up to 3 years old, 10 to 15 feet tall, and 2 inches in diameter at the root collar (Johnson 1979). Trees have been planted with and without top and root pruning in 9-inch diameter auger holes. Other work is being done on growing large seedlings for 1 to 2 years in containers (9 inches diameter by 24 inches tall) and planting seedlings with undisturbed root systems. Potential early benefits are rapid early growth, planting trees large enough that cultivation can be kept to a minimum, and a planting height beyond the range of deer. Early results with this method are very encouraging.

BENEFITS OF CULTURAL TREATMENTS

At the Southern Hardwoods Laboratory, three levels of cultural intensities were tested with six hardwood species. Cultural intensities were: disk (clean cultivation), mow, and control (no treatment). Species were sycamore, green ash, cottonwood, sweetgum, Nuttall oak, and sweet pecan. After four growing seasons, trees in disked plots were significantly taller and had larger diameters than trees in mowed and control. There were no real differences between mowed and control. Disking increased heights from 42 percent for green ash to 130 percent for sycamore over trees in control plots. Diameter increases ranged from 144 percent for cottonwood to 240 percent for Nuttall oak.

Survival was best in disked plots (91 percent), with mowed next (80 percent), and control lowest (76 percent). Disked plots ranged from a low of 84 percent survival for sweetgum to 9 percent with sycamore. Green ash survived best in mowed and control plots with sycamore a close second.

Trees in disked plots had significantly higher foliar N and Ca concentrations and significantly lower P and Mg than trees in mowed and control plots. Trees in mowed plots had significantly lower K than control; those in disked plots were intermediate with no difference between mowed and disked. Although foliar nutrient concentrations were lower for some nutrients in trees in disked plots, if we assume weight to be proportional to size, then nearly twice as much of each nutrient would have been accumulated in trees in disked plots as in mowed and control. Cottonwood had the highest nutrient concentrations for most elements tested. Sycamore was lowest or tied for lowest for N, P, and K; fourth for Ca; and third for Mg.

Cultural treatments, particularly disking, did not cause any significant reductions in soil nutrient levels. One of the major benefits of disking was probably vegetation control. However, it also improves soil structure, water infiltration, gas exchange between the soil and atmosphere, organic matter, and nutrient availability.

SUMMARY AND CONCLUSIONS

Research and experience have solved many of the problems in planting cottonwood and other priority hardwoods. Our recommendations entail intensive site preparation and clean cultivation through at least the first growing season. Proper site selection, good site preparation and cultivation, high quality seedlings, and proper planting techniques are musts if hardwood plantations are to be successful. Planting large seedlings may reduce the costs of site preparation and cultivation. In addition to competition control, other benefits of disking include better soil nutrient and moisture availability, incorporation of organic matter and mineralization, gas exchange between the soil and atmosphere, and improved soil structure.

LITERATURE CITED

Baker, James B., and B. G. Blackmon.
1978. Summer fallowing--a simple technique for improving old-field sites for cottonwood. U.S. Dep. Agric. For. Serv. Res. Pap. SO-142, 5 p. South. For. Exp. Stn. New Orleans, La.

Johnson, R. L.
1978. Hardwood culture in the eastern United States. In Proc. Symp.: Utilization and Management of Alder [Ocean Shores, Wash., Apr. 25-27, 1977]. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. PNW-70, p. 55-59. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Johnson, Robert L.
1979. Adequate oak regeneration--a problem without a solution? Proc. 7th Annu. Hardwood Symp. of the Hardwood Res. Counc., Management and Utilization of Oak [Cashiers, N.C., May 1979], p. 59-65.

Kennedy, Harvey E., Jr., and Wilbur H. Henderson.
1976. Cultivation in cottonwood plantations--practices and equipment. Proc., Symp. East. Cottonwood and Related Species [Greenville, Miss., Sept. 28-Oct. 2, 1976], p. 379-384.

McKnight, J. S.
1970. Planting cottonwood cuttings for timber production in the South. U.S. Dep. Agric. For. Serv. Res. Pap. SO-60, 17 p. South. For. Exp. Stn., New Orleans, La.

McKnight, J. S., and R. L. Johnson.
1980. Hardwood management in southern bottomlands. For. Farmer [23rd Manual Ed.] 39(5): 30-39.

Weber, W. Pat.
1972. What the forest owner is looking for in a hardwood seedling. Proc. Southeast. Area For. Tree Nurserymen's Conf. (Western sess.), p. 5-8.

SITE PREPARATION TREATMENTS AND NUTRIENT LOSS FOLLOWING COMPLETE HARVEST USING THE NICHOLSON-KOCH MOBILE CHIPPER[1]

Robert Gorden[2]
James H. Miller
Conrad Brewer

Abstract.--Site disturbance, vegetation control, and nutrient loss were assessed following complete biomass harvesting of a pine plantation by the Nicholson-Koch mobile chipper. Thirty-two percent of the soil area was significantly compacted to a 10 cm depth. Litter zone material showed a two-fold increase due to chips lost during harvest. Herbicide treatments (Tordon 10K and Velpar Gridball) were applied following harvest. Tordon controlled 84 percent of the hardwood resprouts during the first growing season and Velpar 37%. Tension-cup and -plate lysimeters were used to monitor percolation losses from the soil. During the first 5 months, treatments accelerated losses of Ca, Mg, K, Na, PO_4, NO_3, SO_4, and HCO_3. Loss due to Tordon treatment was greater than chipping alone, for all nutrients analyzed.

As current energy sources continue to increase n cost and decrease in availability, attention as turned toward wood as a renewable fuel source or wood processing and other industries. Nationlly, the wood processing industry is 40 percent elf-sufficient in energy production (Arola 1976) ith the Southeast having the greatest potential ut the lowest utilization at the present time. omplete biomass harvest for fuel is a developing eality (Koch and McKenzie 1976) but the concept aises questions regarding impacts on future site roductivity. The engineering research work unit of the Southern Forest Experiment Station at Auburn, Alabama, is testing a complete biomass harvest system, the Nicholson-Koch Mobile Chipper (Koch and Savage 1980). A mobile-chipper test site was used in this study to assess site preparation potential, surface disturbance, and nutrient-loss impacts after complete biomass harvest.[3]

STUDY AREA

A complete biomass harvest was performed during April, 1980 on a 1-ha study site in the Forestry Department Woodlot, Auburn University. The soil series was a Blanton loamy sand with well developed litter (8 cm) and humus (5-10 cm) layers. Slope on this site ranged from 5-15% with two old terraces on the steeper slopes. A partially-filled gully runs across the center of the area, resulting from past cultivation.

A plantation of 53-year-old mixed loblolly (Pinus taeda) and slash pine (Pinus elliottii) averaging 147 metric tons per hectare (m.t./ha) total standing crop comprised the overstory on approximately half of the area. A shortleaf pine (Pinus echinata) stand averaging 87 m.t./ha covered the other half of the test site. Prevalent midstory species were southen red oak (Quercus falcata), water oak (Quercus nigra), sweetgum (Liquidambar styraciflua), persimmon (Diospyros virginiana), dogwood (Cornus florida), red maple (Acer rubra), and high bush blueberry (Vaccinium sp.).

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If herbicides are handled, applied or sposed of improperly they may be injurious to mans, domestic animals, desirable plants, and llinating insects, fish, or other wildlife, and y contaminate water supplies. Use herbicides only en needed and handle them with care. Follow the rections and heed all precautions on the container bel.

[3] All further references to harvesting on this site are made with the assumption that all standing trees, shrubs, and vegetation were removed at or just above the soil surface; no root harvest occurred.

METHODS

A complete block experimental design was used with three blocks and five .05 ha treatment plots per block. Four of the five treatment plots were completely harvested before applying additional treatments to control hardwood resprouting. The fifth treatment plot in each block remained unharvested and untreated.

The following treatments were assigned randomly and initiated on the four harvested plots in each block:

1. Velpar Gridball - hand applied in a grid pattern at 1.3 kg/ha active ingredient (1 cc formulation[1]).
2. Tordon 10K - using commercial fertilizer spreader with a random scatter effect (small pellet[2]), applied at 5.6 kg/ha a.i.
3. Chipped only - no additional vegetation control measures initiated after harvesting (this plot to serve as a baseline for vegetation response to complete harvest).
4. Windrowing - land clearing by crawler-tractor with a straight blade.

Herbicide treatments were applied on June 18, 1980 after resprouting had begun. Windrowing is scheduled to begin in the fall (1980) prior to winter planting of loblolly pine seedlings.

In the following sections, study methods and results will be presented jointly under separate headings.

SURFACE DISTURBANCE

The degree and coverage of surface disturbance was assessed using seven categories, modified from Dyrness (1967).

1. Undisturbed--the humus layer still in plac and no evidence of compaction.
2. Slightly disturbed--three conditions fit this class:
   a. Humus removed and mineral soil exposed
   b. A1-horizon soil, humus layer, and/or chips intimately mixed with about equal proportions;
   c. A1-horizon soil deposited on top of litter.
3. Deeply disturbed--A1-horizon removed and A2-horizon or deeper soil layers exposed.
4. Compacted (depressed)--obvious compaction due to passage or a wheel and/or track.
5. Debris pile--mixture of debris and chips greater than 10 cm deep.
6. Soil deposition--eroded mineral soil deposited on soil surface.
7. Non-soil areas--stumps or logs.

Five 50- to 60-m transects were installed across the test site at regular intervals and the surface condition at 1-m spaced points was categorized into disturbance classes. Soil core samples were extracted in pairs from compacted (depressed) points and from undisturbed points within 30 cm at 0-5 cm and 5-10 cm depths.[3]

Results from the soil-surface survey are tabulated below.

Classes	Covered (%)
Undisturbed	25.3
Slightly disturbed	28.8
Deeply disturbed	1.1
Compacted	32.4
Debris piles	7.1
Soil deposition	2.8
Non-soil	2.5

Compaction is the most prevalent disturbance affecting about one-third of the area. This is less than a theortical maximum calculated from track- and chassis-width measurements in a complete harvest. If the inside track of the mobile chipper and/or wheels of a towed chip wago followed over the outside track patch of the previous swath then 44 percent of the area would be compacted, while overlapping swaths would result n 66 percent compaction. Our findings is less than he theoretical compaction potential owing to ground rotection afforded mainly by chips from the feller ar operation and also limbs and surface roots. ifferences in bulk density between compacted and isturbed soils were compared using paired t-tests nd were found significant ($p \geq 0.01$) at both he 0.5 cm and 5-10 cm depths. Mean bulk density t the 0-5 cm depth was 1.54 g/cm^3 for compacted nd 1.37 g/cm^3 for undisturbed conditions and at he 10 cm depth 1.58 and 1.42, respectively.

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[1] A 10% active ingredient pellet of hexazinone manufactured by E.I. Dupont de NeMours and Company.

[2] A 10% active ingredient pellet of picloram manufactured by Dow Chemical Company.

[3] Compaction data furnished by Anthony L. King, formerly with the Southern Forest Experimen Station, presently with Agricultural University, Kenya, Africa.

Hatchell (1970) reported that increases in ulk density from 0.17 to 0.20 g/cm^3 in loamy sand nd loam soils reduced shoot weights of 1-year-old oblolly pine by 33 to 43 percent and root weight y 40 to 55 percent. Such a reduction in growth or seedlings on one-third of the areas harvested y the mobile chipper may not occur due to dimiution of compaction effects by continuous-urrow or dibble-planted seedlings. This has not et been determined. Planting by dibble would be ifficult on 7.1% of this area due to deep deposiion of chips and twigs.

HUMUS AND LITTER

Humus and litter were sampled prior to mobile hipping and again following harvest. Samples easuring 0.09 m^2 (1 ft^2) were extracted at six ystematically located points within each treatment lot before harvest, a total of 90 samples. Sample ocations were 4 m from plot corners (45°) and mid oints on the longest sides (90°), with post-harest samples taken immediately adjoining pre-harest sample locations. During pre-harvest sampling he distinct humus and litter layers were separated t the time of collections but post-harvest samples equired mechanical separation by nested sieves of hips and twigs from both litter and humus. Ashing ill be performed on pre-harvest humus samples and ost-harvest humus and litter samples to adjust eights for the mineral soil component. Only humus amples have been ashed at this time.

The chipping operation added 4.5 m.t./ha of hips and twigs to the original litter layer which eighed 2.3 m.t./ha. This 195 percent increase, ue principally to chips, is attributed to feller-ar operation and chip-loss during turns when the hip wagon was not aligned with the chip discharge uct on the chipper. Fewer turns on larger areas r better alignment should decrease this loss. he influence of this large influx of material to he forest floor and resulting impacts on the ineralization processes are not known. These low-utrient, high cellulose chips should decompose lowly releasing nutrients more gradually. Most of he needle and twig component was removed from the ite with harvest. Removal from a forest of the eaf, twig and needle components as typifies comlete biomass harvest, may diminish the available utrient supply necessary for future growth. Waide nd Swank (1975) in their model of nitrogen cycling n a loblolly pine plantation located in North Carolina have indicated a 100 percent increase in nitrogen removal with complete tree harvesting. Additionally they found that with leaf, twig, and needle removal, a substantial decrease in yield may be expected in the third rotation. Cole et al. (1968) in a study of Douglar-fir (Pseudotsuga menziesii) indicated that complete tree removal would more then double nutrient loss from a site following harvest.

NUTRIENT LEACHING

This study has begun to quantify the losses due to leaching following complete biomass chipping and removal, by employing tension lysimeters. Two types of lysimeters were used; tension cup and tension plate.[1] Cups provide soil solution samples with minimum concentration bias due to ceramic adsorption or ion screening. Plates allow calculations of loss on an area basis. Description of these devices and installation procedures can be found in Miller (this same conference). Prior to installation all lysimeters were washed with distilled water to eliminate ceramic contaminants.

Leaching losses are being monitored on the following three treatment plots within each block: (a) unharvested check; (b) chipped only (completely harvested) plots[2]; and (c) complete harvest plus herbicide control (Tordon 10K at 5.6 kg/ha a.i.). Lysimeters were installed below the lateral rooting zone at 60 cm. All installations occurred during the 3-week period following harvest completion. Lysimeters were placed just below the maximum lateral rooting zone to reflect true losses from the system. Lysimeters were systematically grouped into two units, with a central plate, and two cups (three in the check) as satellites at a distance of 3.6 m within monitored plots. A total of 18 plates and 42 cups have been installed on this study site.

All devices are evacuated to 0.2 bars which approximates Field Capacity moisture tensions. Percolating water that is held with less than 0.2 bars of tension may pass through the ceramic elements to be collected. Precipitation inputs are being quantified by 1 recording and 2 non-recording gages on the area.

Calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) are being analyzed in soil solution and precipitation samples using standard techniques of atomic adsorption spectrophotometry.

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[1] Both lysimeters are modified versions of commercial models manufactured by Soil Moisture Equipment Corp., Santa Barbara, California.

[2] This treatment plot to serve as a baseline for nutrient response following complete harvest, with no additional attempt at vegetation control.

Sulfate (SO_4) determinations are by the barium-chloride gel technique (Tabatabai 1974). Phosphate (PO_4), nitrate (NO_3), bicarbonate (HCO_3), and pH are determined using standard methods (McRand et al. 1976).

A substantial increase in leaching loss has occurred due to complete tree chipping and removal (Table 1). The use of herbicide for resprout control has accelerated this loss for all nutrients studied except phosphorus which has shown only a small increase in loss due to herbicide treatment. Bicarbonate and nitrate are the most concentrated anions responsible for cation leaching in this soil system. This data indicate that ecosystem recovery and on-site nutrient immobilization have not yet begun. The difference between nutrient loss in chipped plots and that incurred with herbicide application is probably attributed to root development and nutrient uptake by the reassurging vegetation.

HERBICIDE CONTROL

First year vegetation control by herbicide treatments was assessed by complete stem counts within three treatments plots; Tordon, Velpar, and Chipped Only. Sprouts were categorized as either uninjured, injured or dead. A tabulation of mean total hardwood stems per hectare reveals further the effectiveness of treatments; Chipped plots averaged 17,200 stems, Velpar plots 14,700 and Tordon 11,700.

Tordon plots demonstrated the most effective early control for hardwood, shrub, and woody-vine regrowth (Table 2), averaging 84 percent of all stem counted as injured or dead. Those plots in which Velpar was applied demonstrated some vegetation control, but suppressed only 37 percent of all stems The chipped-only plots (no herbicide applied)had the lowest incidence of stem death or injury, averaging only 5 percent. The average per hectare was 14,550 hardwoods, 7850 shrubs, and 5912 vines.

Tordon was most effective against blueberry, sweetgum, red maple and grape controlling over 95 percent of these sprouts. It was least effective against the oaks but controlled an impressive 71 percent.

Velpar has to date been less effective in vegetation control than Tordon. Greatest control by Velpar was found in red maple, while control in excess of 50 percent occurred only in the red oak group. The impact of damage to vegetation by insects, water stress, and disease in the Tordon and Velpar plots may be discounted. The highest per-species injury rate in the chip-only plots, though not attributable to herbicide action, was used to create a baseline for separating true herbicide damage from natural injury of death, in the Tordon and Velpar plots.

Table 1. Areal precipitation inputs and leaching losses for eight nutrients from a completely harvested mixed pine plantation on Blanton loamy sand, collections 5/10 to 10/11/80.

	Inputs[1]		Losses		
Nutrients	Min.	Max.	Unharvested Check	Chipped	Chipped and Herbicide
	g/ha				
Ca	265	733	58	826	1355
Mg	337	487	46	574	786
K	874	2063	83	732	846
Na	1001	1295	220	1670	2495
NO_3-N	966	1778	60	1161	2363
PO_4-P	59	147	0	15	16
SO_4-S	2185	4972	9	834	2225
HCO_3-C	1297	1812	400	3719	4696

[1] Minimum inputs calculated using the lowest concentrations of three raingages, presumably minimum additions of bird droppings and insects, and maximum inputs used mean concentrations.

able 2. Early results of vegetation control from three treatments on a completely harvested mixed pine planatation, Auburn University Woodlot.

pecies	Vegetation Control Treatments		
	Chip Only	Chip and Velpar	Chip and Tordon
	% Damage[1]	% Damage	% Damage
ardwoods			
Red Oak[2]	6a[3]	53b	71b
Sweetgum	8a	40b	100c
Red Maple	8a	89b	100b
Others[4]	2a	37b	93c
otal	2a	47b	76c
hrubs			
Blueberry	9a	28b	97c
Others[5]	6a	31a	59a
otal	8a	28b	92c
ines			
Grape	4a	36b	97c
Greenbrier	4a	33b	70c
otal	5a	36b	84c

/Includes dead and injured.

/Refers to the Red Oak group with several species represented.

/Means in a row followed by a different letter are significantly different at the 5% level.

/Includes hickory, yellow poplar, persimmon, sassafras, black locust, elm, black cherry, blackgum, beech, magnolia, and American hornbeam.

/Includes hawthorn, sumac, and bayberry.

DISCUSSION

Forest managers have a responsibility to nderstand the balance and regulation of nutrient ycling in a forest ecosystem. Nutrient inputs y precipitation, mineral weathering, dry fallout nd fertilization as well as losses by biomass emoval, leaching and gaseous losses must be egulated by a modern management approach. ontinued site productivity and the renewable ature of the forest resource depends upon this nowledge and regulation. The significance of arvest removal of nutrients may be most critical here complete biomass harvesting occurs and here on-site nutrient capital is low to marginal.

Several studies (Wells and Jorgenson 1975, Weetman and Weber 1972, Pritchett and Smith 1974) have demonstrated the significant increase in nutrient loss when whole tree harvest has occurred. Development of the Nicholson-Koch Mobile Chipper may make possible even greater utilization of the material typically left following harvest, while producing a corresponding increase in nutrient removal.

Future research will quantify major contributing components of the nutrient cycle on this site. Litter, humus, chip and soil nutrient budgets will be determined, while monitoring of leaching loss and precipitation input will continue. It may be important to note that when this or similar harvest systems are used, alteration of the cutting schedule to occur before spring leaf-out may contribute significantly to continued site productivity, especially on typically poor quality sites, Also, the importance of minor essential nutrients that have been removed through harvest may become critical to future site productivity, and therefore an attempt will be made to assess these losses in further efforts.

LITERATURE CITED

Arola, R. A.
1976. Wood fuels-how do they stack up? p. 34-45 In Energy and the Wood Products Industry. Proc. For. Prod. Res. Soc.

Cole, D. W., S. P. Gessell and S. G. Dice
1968. Distribution and cycling of nitrogen, phosphorus, potassium and calcium in a second-growth Douglas-Fir Ecosystem. p. 197-232 In: H. E. Young, ed, Symp. Primary Prod. Miner Cycling Natur Ecosyst., ed. Univ. Maine Press.

Dyrness, C. T.
1967. Soil surface conditions following skyline logging. U.S. Dep. Agric. For. Serv. Pac. NW Exp. Stn., Res. Note No. 55, 8 p.

Hatchell, G. E.
1970. Soil compaction and loosening treatments affect loblolly pine growth in pots. U.S. Dep. Agric. For. Serv. SE Exp. Stn., Res. Pap. No. 72, 9 p.

Koch, P. and T. E. Savage.
1980. Development of the swathe-felling mobile chipper. J. For. 78:17-21.

Koch, P. and D. W. McKenzie.
1976. Machine to harvest slash, brush, and thinnings for fuel and fiber--a concept. J. For. 74-809-812.

McRand, M. C., A. E. Greenberg and M. J. Raras, ed
1976. Standard methods for the examination of water and waste water, 14 ed.

Pritchett, W. L. and W. H. Smith.
1974. Management of wet savanna soils for pine production. Fla. Agr. Exp. Sta. Tech. Bul. 76
22p.

Tabatabai, M. A.
1974. Determination of sulphate in water samples
Sulphur Inst. J. 10:11-13.

Waide, J. B. and W. T. Swank
1976. Nutrient recycling and the stability of ecosystems: Implications for forest renewable
source potential 1975: The turning point. Proc. 1975 Nat. Conv. Soc. Amer. For. Wash. D.C.

Weetman, G. F. and B. Weber
1972. The influence of wood harvesting on the nutrient status of two spruce stands. Can. J. For. Res. 2:351-369.

Wells, C. G. and J. R. Jorgenson.
1975. Nutrient cycling in loblolly pine plantations. p. 137-138 In: B. Bernier and C. H. Winget, eds. Forest Soils and Forest Land Management, Laval Univ. Press, Quebec.

DIRECTED-SPRAYING DICHLORPROP FOR PINE RELEASE[1]

Robert F. Lowery[2]

Abstract.--Young loblolly pine (Pinus taeda L.) plantations can be released from hardwood competition using dichlorprop as a directed-spray. Contract labor quality performance incentives have produced good hardwood control at costs somewhat higher than aerial spray costs. Spraying begins once leaves are fully expanded in spring and continues until early July. Difficult-to-control hardwoods can be killed if given thorough coverage early in the season. Pines will be damaged if sprayed accidentally.

INTRODUCTION

The suspension of forestry uses of 2,4,5-T ft the Southeast United States without an fective herbicide for selectively releasing uthern pine from hardwood competition. Approxi- tely 240,000 ha of pine lands are being encroached on annually by hardwoods in the Southeast alstad 1976). The search for herbicides to lectively control hardwoods on these areas at acceptable cost continues with glyphosate, xazinone and triclopyr receiving the most tention in current tests.

DEVELOPMENT

Weyerhaeuser has some 4,000 ha of loblolly ne plantations in Southwest Arkansas annually aching the point where release is necessary. th no proven selective herbicide to use, for- ters in this region began experimenting in 1979 th directed-spraying using backpack sprayers. is is not a new concept for southern pine lease as even 2,4,5-T was applied in this nner on areas: (1) where drift would be a oblem, (2) that were too small for economical rial application, or (3) that were too steep r mist blower operation. In the 1979 tests, th Weedone^{R} 170, a 50:50 mixture of 2,4-D and 4-DP or dichlorprop, and Weedone^{R} 2,4-DP, chlorprop only, were applied to hardwood brush young loblolly pine plantation test plots. It soon became evident that Weedone 170 was producing considerably more pine damage than dichlorprop alone when inadvertently applied to pines, but hardwood control was essentially the same with both herbicides. The 2,4-D component of Weedone 170 probably was responsible for the increased pine damage. Areas sprayed with dichlorprop exhibited little pine damage unless the pines were sprayed deliberately.

Based on these results, Union Carbide obtained 24-C labels in Alabama, Arkansas and Mississippi to use dichlorprop as a directed-spray to control unwanted hardwoods in young pine plantations. During 1980 some 6,000 ha of pine plantations were treated on Weyerhaeuser lands in Arkansas. This paper reviews the techniques used in this directed-spray program and summarizes the results obtained as of early September, 1980.

PRESENT PROGRAM

The 1979 trials and the first weeks of the 1980 spray season clearly demonstrated the necessity of careful herbicide application to meet our goal of good hardwood control and minimal pine damage. Attention to quality control through each phase of the operation has given the desired level of brush control and the use of contract labor crews for application has allowed us to meet this goal at an acceptable cost.

Contractors are paid on a per-hectare basis with a quality incentive built into the payment schedule. Payment is made after herbicide symptoms begin to appear, i.e. one to two weeks after application. At that time, a Company inspector checks treated areas for: (1) coverage of assigned area, (2) coverage of brush less than 1.2 m tall, (3) coverage of brush greater than 1.2 m tall, and (4) pine damage. The contractor is paid a percentage of the previously negotiated per-acre contract price based on the quality of work in each of these four categories. In 1980, contractor directed-spray application costs were approximately 50% higher per-hectare than the cost of aerial applications.

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[1] Paper presented at Southern Silvicultural search Conference, Atlanta, Georgia, November 7, 1980.

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The Company provides the pre-mixed spray solution to the contractor at the plantation site to insure mixture uniformity. The mixture is prepared by adding one part of 480 g L^{-1} dichlorprop to 24 parts of water. A surfactant, Triton^{R} AG-98, is added at the rate of one part surfactant to 320 parts of the dichlorprop/water mixture.

Spraying begins once hardwood leaves are fully expanded in spring and continues until early July. As with many other foliage applied herbicides, dichlorprop efficacy decreases as the summer season progresses, hence the early July cut-off date.

In the field, the directed-spray crew typically consists of 10 people; each crew member owns the backpack type sprayer used. The crew members walk through the plantation abreast of one another spraying a 3 m wide swath of brush as they go. The laborers are instructed to spray to just short of the point of runoff. They are lead by the fastest working person and trailed by the slowest; the latter occasionally ties plastic flagging to mark the edge of the area just sprayed.

Directed-spray treatment is easiest when the hardwoods are small, i.e. less than 1.5 m tall. It is easier for workers to move through young plantations and thorough spray coverage of the competing stems can be accomplished quicker and with less herbicide than if larger trees are treated. Accidental spraying of pines also is reduced since nozzles usually are directed down over the tops of short competing stems. Pine growth also will be enhanced if they are essentially free-to-growth from an early age rather than being left until strong hardwood competition develops as was often done when releasing aerially with 2,4,5-T (Balmer et al. 1978, Langdon and Trousdell 1974, Roberts 1960). The value of these reportedly large growth gains far outweighs the somewhat higher cost of directed-spray treatment relative to aerial applications. Therefore, our directed spray program is aimed at two- to three-year-old pine plantations. Plantations that are going to have severe hardwood competition can be identified easily at this time.

RESULTS

Pines will be killed if sprayed thoroughly with the dichlorprop spray mixture. However, accidental contact with portions of the crown will kill only that portion of the foliage sprayed. Our assessments indicate that 40% of the pines exhibit some sign of herbicide contact, but this figure is understandable considering the intimate contact between hardwood and pine foliage in plantations in need of release. The level of damage on individual trees generally is not high.

Dichlorprop applied as a directed-spray has been effective in controlling most hardwood competition. Even red maple and ash can be controlled if given thorough coverage early in the spray season. A variety of plantations treated in the spring of 1980 were sampled in early September to assess the level of competition control. Only stems greater than one-half the height of nearby pines were included in the following summarization.

Species	Frequency %	Defoliation %
Sassafras (Sassafras albidum) (Nutt.) Nees	1	100
Persimmon (Diospyros virginiana) L.	1	97
Sumac (Rhus spp.) L.	21	94
Black-gum (Nyssa sylvatica) Marsh.	22	93
Hawthorn (Crataegus spp.) L.	1	85
Sweetgum (Liquidambar stryraciflua) L.	7	81
Black Cherry (Prunus serotina) Ehrh.	1	79
Elm (Ulmus spp.) L.	1	75
Red Oak (Quercus spp.) L.	11	70
White Oak (Quercus spp.) L.	8	69
Hophornbeam (Ostrya virginiana) [Mill.] K. Koch	1	68
Dogwood (Cornus florida) L.	9	57
Hickory (Carya spp.) Nutt.	11	45
Red Maple (Acer rubrum) L.	4	30
Ash (Fraxinus spp.) L.	1	10

SUMMARY

A directed-spray with a 4% dichlorprop solution plus surfactant gives good control of st hardwood brush competition in young pine antations in Southwest Arkansas. In addition, netary incentives to contract applicators for ality work has contributed to obtaining these sults at a reasonable cost. Treating plantations a young age before the hardwoods reach 1.5 m height improves treatment efficacy, reduces cidental spraying of pines, reduces labor and terial costs and leaves pines in a free-to-grow ndition at an earlier age than if the treatment delayed. This technique offers an alternative aerial application of 2,4,5-T for pine release til an effective alternative aerial release rbicide treatment is available.

LITERATURE CITED

lmer, W. E., K. A. Utz and O. G. Langdon.
1978. Financial returns from cultural work in natural loblolly pine stands. S. J. App. For. 2(4):111-117.

ngdon, O. G. and K. B. Trousdell.
1974. Increasing growth and yield of natural loblolly pine by young stand management. Proc. Symp. Management of Young Pines. Charleston, S.C. 1974. p. 288-296.

berts, G. E.
1960. A progress report on the ability of small pines to compete with hardwood sprouts. Miss. State Univ. Ag. Exp. Sta. Bul. 621, 8 pp.

lstad, J. D.
1976. Weed control for better southern pine management. Weyerhaeuser Forestry Paper No. 15. 44 pp.

DISCONTINUOUS MOUNDING AS A SITE TREATMENT ON A FLATWOODS SOIL[1]

James D. Haywood[2]

Abstract.--After four growing seasons, slash pines on treated plots (planted by hand on 38-cm and 75-cm high discontinuous mounds of topsoil formed by a crawler tractor on a very gently rolling Caddo-Messer silt loam complex) averaged 38 percent larger root-collar diameter and were 25 percent taller than pines planted on untreated plots. Slash pines grew equally well on both mound sizes. Discontinuous mounding did not hinder surface drainage, as continuous bedding on a very gently rolling silt loam soil often does.

INTRODUCTION

Bedding by conventional methods often only marginally increases height and volume growth in slash pine (*Pinus elliottii* Engelm. var. *elliottii*) plantations on flatwoods soils of the West Gulf Coastal Plain (Derr and Mann 1977, Cain 1978, and Haywood, In press). Pine survival is normally acceptable without planting on beds because most forested flatwoods of the West Gulf Coastal Plain are somewhat poorly drained rather than poorly drained (Derr and Mann 1977). Bedding improves local drainage, but the improvement can be nullified on very gently rolling silt loam soils because water stands in adjacent furrows at low points along the beds (Shoulders and Terry 1978). If average midwinter depth to free water exceeds about 45 cm on untreated sites, pine growth is acceptable without planting on beds (McKee and Shoulders 1970). On a very gently rolling silt loam flatwoods, the depth to free water may exceed 45 cm under pimple mounds, but be at the soil surface in intermound depressions.[3] So pine response to bedding on such sites may be highly variable. And planting on beds may increase the susceptibility of pines to fusiform rust (caused by *Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme* Burdsall and Snow), which can decrease survival (Haywood, in press).

Derr and Melder[4] informally tested discontinuous mounding on a Wrightsville (Typic Glossaqualf, fine, mixed, thermic) and Vidrine (Glossaquic Hapludalf, coarse-silty over clayey, mixed, thermic) silt loam complex to determine if artificial mounds would increase pine growth where the water table is at the soil surface in winter. Afte 6 years, slash pine survival was 6 percentage point higher on discontinuous mounds than on check plots. Trees on discontinuous mounds averaged 56 percent larger d.b.h. (diameter at 1.37 m above groundline) and were 46 percent taller than slash pines on chec plots, while slash pines on bedded plots averaged 17 percent larger d.b.h. and were 11 percent taller than trees on check plots. The early success of discontinuous mounding on this site led to further evaluations on a different very gently rolling flatwoods soil.

SOIL DESCRIPTION

The study area is located in central Louisiana on a Caddo (Typic Glossaqualf, fine-silty, siliceou thermic) and Messer (Haplic Glossudalf, coarse-silt siliceous, thermic) silt loam complex. The Messer silt loam is a deep, moderately well drained, slowl permeable soil developed from loam deposits. It occurs in the complex on convex circular mounds tha are up to 21 m in diameter, and 75 cm in height. Size and frequency of mounds vary greatly but as many as 10 per hectare may be present. The Caddo silt loam is a poorly drained, slowly permeable soi

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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[3] Haywood, J. D. 1979. Site treatment and fertilization to stimulate growth of slash pine on a poorly drained Wrightsville silt loam soil. Progress report of study FS-SO-1102-9.23. Southern Forest Experiment Station, Pineville, Louisiana.

[3] Ibid.

[4] Derr, H. J., and T. W. Melder. 1973. Site treatment and fertilization to stimulate grow of slash pine on a poorly drained Wrightsville sil loam soil. Study Plan FS-SO-1102-9.23. Southern Forest Experiment Station, Pineville, Louisiana.

ormed in deep loamy materials of nearly level
erraces of mid to early Pleistocene age. The study
rea was divided into two topographic classes--an
levated flat of Caddo and Messer soils and a
epression of Caddo soil. The depression forms a
ircular swale of about 0.4 ha and has very poor
urface drainage.

VEGETATIVE COVER

The study area was kept relatively clean of
hrubs and trees by periodic burning. But there
ere scattered clusters of southern bayberry (*Myrica*
erifera L.), post oak (*Quercus stellata* Wangenh.),
nd blackjack oak (*Q. marilandica* Muenchh.) on the
addo-Messer flat, and a few isolated blackgums
Jyssa sylvatica Marsh. var. *Sylvatica*) in the
wale.

Burning ended when the study was installed,
nd density of shrub and trees increased. After
years, topographic features could be distinguished
vegetative cover. Southern bayberry was very
ommon on the elevated flat but lacking in the de-
ession. Buttonbush (*Cephalanthus occidentalis*
) was found only in the swale.

METHODS

After prescribed burning, rectangular,
.25-m x 61-m plots were established in a rando-
zed complete block design with two blocks in
ch topographic class. Two discontinuous mound-
g treatments and an untreated check were estab-
shed in each block. Mounds were formed in late
tober 1975. In the first mounding treatment, a
hn Deere T350 crawler tractor equipped with a
raight, 1.8-m wide dozer blade was used to push
piles of topsoil that averaged 38 cm high and
d a 1.2-m x 1.8-m base. Mounds in the second
eatment averaged 75 cm high. Within rows, mounds
re spaced 6.1 m apart, center to center. Rows of
unds were spaced 3.05 m apart, center to center.
jacent rows were offset in a staggered pattern.
is arrangement allowed for 537 mounds per hec-
re. It took 11 hours to treat a single hectare.

After the mounds had settled, three uni-
rmly graded slash pine seedlings were handplanted
each mound at 60 cm intervals in February 1976.
treated check plots were planted at the same
te and spacing used on mounded plots. After the
rst growing season, one tree was rogued from
ch mound, or planting spot, if all trees sur-
ved. Criteria used in roguing were the presence
bole fusiform rust galls, spacing on the mounds,
d seedling vigor.

Survival, bole fusiform rust infection,
ameter at near groundline, and seedling height
re measured at stand age 4. Survival and fusi-
rm rust percentages were converted to arc sine
roportion before analysis. Individual tree data
were averaged on a plot-by-plot basis. Using analyses of variance (0.05), I analyzed treatment effects separately by topographic class, and I pooled blocks to test for topographic differences and topography-treatment interaction. I used Duncan's Multiple Range Test to isolate differences between individual treatments.

RESULTS

At stand age 4, slash pine survival averaged 91 percent among rogued pines.

Occurrence of bole fusiform rust galls among surviving trees averaged 67 percent. Incidence of rust was similar on both topographic classes.

Percent survival and stem fusiform rust infection of slash pine after four growing seasons

Topographic class/ treatment	Survival	Trees infected with bole fusiform rust
	Percent	Percent
Caddo-Messer flat		
Check	86 a*	62 a
Low mound	94 a	63 a
High mound	90 a	75 a
Average	90	67
Caddo depression		
Check	92 a	66 a
Low mound	92 a	73 a
High mound	91 a	65 a
Average	92	68

* Means within each column followed by the same letter are not significantly different (0.05).

Discontinuous mounding improved the growth of slash pine, but size of mounds made no difference (table 1). Slash pines averaged 38 percent greater diameter and had 25 percent greater height per tree on mounds than did slash pine on check plots. Height growth during the fourth growing season was greater on mounds than on check plots. So pines on mounds were still growing faster than pines on check plots. Pines not infected with fusiform rust had similar results. Uninfected slash pines planted on mounds averaged 39 percent larger diameter, were 29 percent taller, and grew 37 percent more in height during the fourth growing season than did uninfected pines on check plots.

When treatments were averaged, tree diameter and height did not differ significantly between the Caddo-Messer flat and Caddo depression (table 1). All pines in the depression outgrew pines on the flat during the fourth growing season. But 4th-year height growth of uninfected pines did not differ between topography classes.

DISCUSSION

Had this soil complex been bedded instead of mounded, surface drainage from the depression and between the Messer mounds would have been blocked, and the impounded water would probably have limited pine diameter and height growth.[5] Discontinuous mounding did not restrict natural surface drainage. So growth was comparable over the entire tract, though the depression was a wetter site than the flat.

Height of mounds (38 cm vs 75 cm) was not important because slash pine can develop an adequate root system if the average midwinter depth to free water is about 45 cm. Providing depth beyond 45 cm for root growth has little added benefit. In fact, heights of mounds should be prescribed according to average winter depth to free water that is under distinguishable topographic classes. Such prescriptions may reduce per hectare costs. Pimple mounds, for example, probably drain deeply enough and would not need mounding. Flats between pimple mounds may or may not need mounded planting spots, depending on soil drainage. But depressions that are intermittent on the flats would need mounded planting spots for best diameter and height growth. And the mounds would have to be taller than the mounds formed on flats.

Continuous beds are less costly to form than discontinuous mounds. So using both bedding and discontinuous mounding on the same tract according to topographic conditions may be best. The same tractor used to pull the bedding plow could form the mounds. Surface features can be distinguished either after prescribed burning or by changes in vegetative cover. Beds, which are normally 25 cm tall from furrow to crest, could be confined to flats. Discontinuous mounds would be formed only in depressions, so surface runoff would not be restricted in the swales and the greater height of mounds (38 cm or taller) would help root development.

LITERATURE CITED

Cain, M. D.
1978. Planted loblolly and slash pine response to bedding and flat disking on a poorly drained site--an update. U. S. Dep. Agric. For. Serv. Res. Note SO-237, 6 p., South. For. Exp. Stn., New Orleans, La.

Derr, H. J., and W. F. Mann, Jr.
1977. Bedding poorly drained sites for planting loblolly and slash pines in southwest Louisiana. U. S. Dep. Agric. For. Serv. Res. Pap. SO-134, 5 p., South. For. Exp. Stn., New Orleans, La.

Haywood, J. D.
1980. Planted pine fail to respond to mechanica treatments on an Acadia-Beauregard-Kolin silt loam site. U. S. Dep. Agric. For. Serv. Res. Note SO-259, 4 p., South. For. Exp. Stn., New Orleans, La.

McKee, W. H., Jr., and E. Shoulders.
1970. Depth of water table and redox potential of soil affect slash pine growth. For. Sci. 16:399-402.

Shoulders, E., and T. A. Terry.
1978. Dealing with site disturbances from harvesting and site preparation in the lower coastal plain. In Proc. Symp. Principles of Maintaining Productivity on Prepared Sites, p. 85-97, Miss. State Univ., Starkville.

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[5] Derr, H. J., and T. W. Melder. 1975. Discontinuous mounds for planting poorly drained sites. Study Plan for Study FS-SO-1102-9.43. Southern Forest Experiment Station, Pineville, Louisiana.

Table 1.--Slash pine measurements at stand age 4

Topographic class/treatment	All surviving trees			Trees without bole fusiform rust cankers		
	Diameter	Total height	Height growth during 4th growing season	Diameter	Total height	Height growth during 4th growing season
	cm	m	m	cm	m	m
Caddo-Messer flat						
Check	3.58 a*	1.84 a	0.515 a	3.84 a	2.15 a	0.686 a
Low mound	4.95 b	2.25 cd	0.671 b	5.41 b	2.69 b	0.936 b
High mound	4.83 b	2.18 bc	0.677 b	5.21 b	2.64 b	0.972 b
Average	4.45	2.09	0.621	4.82	2.49	0.865
Caddo depression						
Check	3.86 a	1.96 ab	0.604 b	4.14 a	2.21 a	0.738 a
Low mound	5.31 b	2.56 d	0.747 c	5.66 b	2.99 b	1.012 b
High mound	5.46 b	2.51 cd	0.735 c	5.89 b	2.92 b	0.969 b
Average	4.88	2.34	0.695	5.23	2.71	0.906

* Means within each column followed by the same letter are not significantly different, Duncan's Multiple Range Test (0.05).

THE EFFECTS OF SITE PREPARATION ON GROWTH OF LOBLOLLY PINE IN SOUTHEASTERN LOUISIANA[1]

Shih-Chang Hu and Voradeth Ditthavong[2]

Abstract.--A study was made to determine the response of regular and genetically improved loblolly pine (*Pinus taeda* L.) seedlings to three different site preparations. Results at the end of the first growing season indicated that chopping plus burning was superior to chopping only and to intensive site preparation in terms of seedling survival and height growth.

INTRODUCTION

It is general knowledge that today's consumption of wood and wood products is increasing by leaps and bounds. Miller (1978) pointed out that the need for wood will far exceed the rates of production in the next 25 to 30 years. Moreover, the decrease of forest land is a chronic phenomenon here in the South, especially in Louisiana. This is due to a rapid expansion of urban and industrial zones. Another type of forest acreage loss stems from land clearing for uses that will provide a higher rate of return to the owner than that gained from forest activities (Marlin 1978).

Such circumstances generate the problem of accelerating wood production on decreasing forest areas. However, Haines et al. (1975) affirmed that future demands for timber could be satisfied if better forestry were utilized. To these authors, better forestry refers essentially to "successful regeneration and subsequent use of the full capabilities of the land." Haines et al. (1975) laid stress on the importance of site preparation, which is a prerequisite for forest renewal.

Although intensive site preparation -- chopping, disking, and ditching -- represents a popular practice in the South, many investigators have found that its need and desirability still remain in question. For intensive site preparation has not only proven to be expensive, it may deteriorate the site and jeopardize long-term forest productivity as well (May et al. 1973, Hebb and Burns 1975, Haines et al. 1975, Schultz 1975, Sundra and Lowry 1975, Moehring 1977).

The basic objective of this study was to determine the effects of site preparation on the growth of hand-planted loblolly pine (*Pinus taeda* L.), which is the most important timber species in the South. A subsidiary objective was to compare the rate of growth of regular seedlings with genetically improved seedlings.

METHODS AND PROCEDURES

Description of Experimental Area

This study was conducted on the LSU Idlewild Experiment Station near Clinton, Louisiana.

The average annual rainfall in this area is approximately 158 centimeters. The distribution of precipitation is fairly uniform throughout the growing season. The average temperature is 8.9°C for January and 26.7°C for July. The frost-free period averages about 247 days yearly.

The main forest type in Idlewild is pine or pine-hardwood with loblolly and shortleaf pines as dominant timber species. The site index for loblolly pine is about 100 in this experiment station.

Field Procedure

The plantations were hand-planted on recently clearcut sites in early February and March 1979. They consisted of three 0.80-hectare rectangular ocks which received the following preplanting te treatments:

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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Treatment (Block) 1: chopped only;
Treatment (Block) 2: chopped and burned;
Treatment (Block) 3: chopped, burned, stumps removed, and double disked.

Each block was divided into two 0.40-hectare ots, one of which was hand-planted with 1-0 gular and the other with 1-0 genetically improved blolly pine seedlings at 2.4 by 2.4-meter spacing spectively. Within each plot there were four plications consisting of 100 trees each, planted 10 rows of 10 trees each (a 0.06-hectare sub- ot). Thus there were a total of 24 measurement bplots. To minimize border effects, a strip of 8 meters wide was established around each subplot.

The planting stocks were obtained from the uisiana Office of Forestry's nursery in DeRidder, uisiana. The genetically improved and regular edlings were treated the same in the nursery. e improved seedlings came from seed collected om an open-pollinated, unrogued seed orchard.

The initial height of each seedling was asured in April 1979, before height growth gan. The height growth and survival rate at e end of the first growing season was made in nuary 1980.

Statistical Analysis

Paired t-tests were used to test the signi- cance of difference between the average height owths and survival rates of the regular and netically improved seedlings planted on each eatment or block.

Comparisons of the average height growths the seedlings between treatments or blocks were de by a least squares analysis of variance using t-test.

RESULTS AND DISCUSSION

Survival and Treatment

The average survivals for each of the three eatments are presented in Table 1. It appears at the best survival (86.5 percent) occurred on opped and burned plots, and the lowest (71.4 rcent) on the most intensively treated plots reatment 3). The treatment which involved only opping had an intermediate rate of survival 7.8 percent). The results noted in this study e in contrast to the observations made by Wells d Crutchfield (1974). The two investigators und that the more intensive the treatment learing with a KG blade plus windrowing plus uble disking), the greater the survival.

The cause of low survival in treatment 3 may be because the seedlings were planted too soon after disking. It has been reported that planting on freshly disked soil can result in 40 to 50 percent mortality in the first or second month even if the soil is moist (Mann 1974).

The best survival in treatment 2 was probably due to beneficial effects provided by chopping and burning. McNab and Ach (1977) remarked that one year after planting loblolly pine seedlings planted in ashes of burned logging slash had five times greater survival than those planted away from the ashes.

The difference in survival between treatment 1 and treatment 3 (77.8 percent versus 71.4), though not substantial, may illustrate the adverse effect of soil disturbance which reduced productivity of the site.

Survival and Type of Planting Stock

At each level of site preparation, the survival of regular trees was greater than that of genetically improved trees (Table 1). The range in average survival was from 78 to 91 percent for ordinary planting stock and from 65 to 82 percent for superior material.

Both varieties of loblolly pine survived best on treatment 2 (Block 2), second best on treatment 1 (Block 1), and less on treatment 3 (Block 3).

There is a statistically significant difference in favor of regular seedlings at the 5 percent level of probability. On the average, the regular seedlings had a survival rate of 83.7 compared to only 73.7 percent for genetically improved seedlings.

These results, however, do not support the evidence provided by Dutrow and Row (1976), in which the survival of superior seedlings was greater than that of regular seedlings.

On the basis of this study, inappropriate environment and conditions were perhaps the main cause of the inferior performance of genetically improved trees. According to Goddard et al. (1975), the best genetic stock never produces its full potential if soils having critical nutrient deficiencies are not fertilized.

Height Growth and Treatment

The average height growths of loblolly pine at the end of the first growing season are shown in Table 1 and illustrated in figure 1. The best height (28.95 centimeters) was found in plots which were chopped and burned, and the lowest (20.06 centimeters) in chopped, stumps removed, and double disked plots. The trees that received chopping only had an intermediate height growth (22.35 centimeters).

Table 1.--Relationship of site preparation treatment and seed origin to first-year survival and height increment of 1-0 loblolly pine seedlings

Site preparation treatment	Regular		Genetically improved		Average	
	Surv.	Ht. inc.	Surv.	Ht. inc.	Surv.	Ht. inc.
	Percent	Cm	Percent	Cm	Percent	Cm
Chopped	82.0	23.1	73.5	21.6	77.8	22.35
Chopped, burned	90.8	33.0	82.3	24.6	86.5	28.95
Chopped, burned, stumps removed, and double disked	78.0	21.1	64.8	17.8	71.4	20.06
Average, 3 treatments	83.7	25.7	73.7	21.7	78.6	23.7

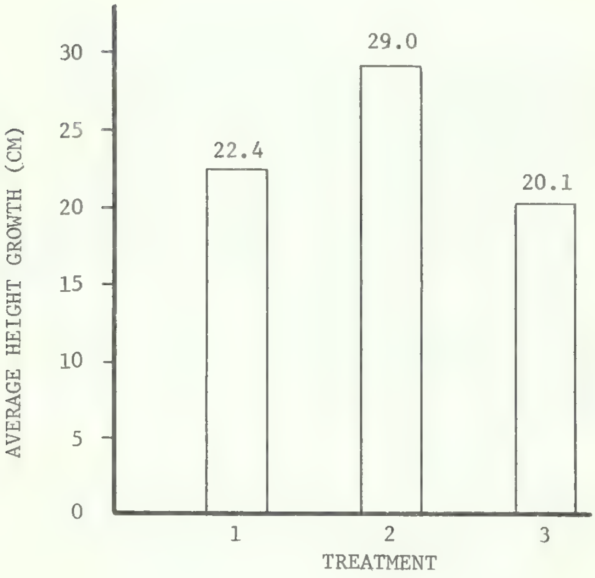


Figure 1.--Average first-year height growth of loblolly pine grown on three differently prepared sites.

Trees on treatment 2 (chopped and burned) averaged 8.89 centimeters (44.3 percent) and 6.60 centimeters (29.5 percent), respectively, taller than those on treatment 3 and treatment 1. The average height of trees grown on treatment 1 (chopped only) was 2.29 centimeters (11.4 percent) greater than that of those on treatment 3. The comparisons of the average height growths of loblolly pine seedlings indicated that the differences were statistically significant at the 1 percent level of probability.

As with the case of survival, the results obtained for average height growth in this study were also in contrast with the findings revealed by Wells and Crutchfield (1974) and Hunt and Cleveland (1978), in which the tree heights increased with the intensity of site preparation.

On the basis of the present investigation, it is difficult to know exactly what factors affected the height growth of the seedlings. But, the beneficial effect created by burning of logging slash and less intense competition from ground cover vegetation appeared to be one of the probable causes of the improved height growth in treatment 2. McNab and Ach (1977) reported that, at age one, the average height growth of seedling planted in ashes of burned logging slash was more than twice that of seedlings not in the ashes. Lennartz and McMinn (1973) noted that increases in height growth were related to the degree of disturbance or reduction of competing vegetation.

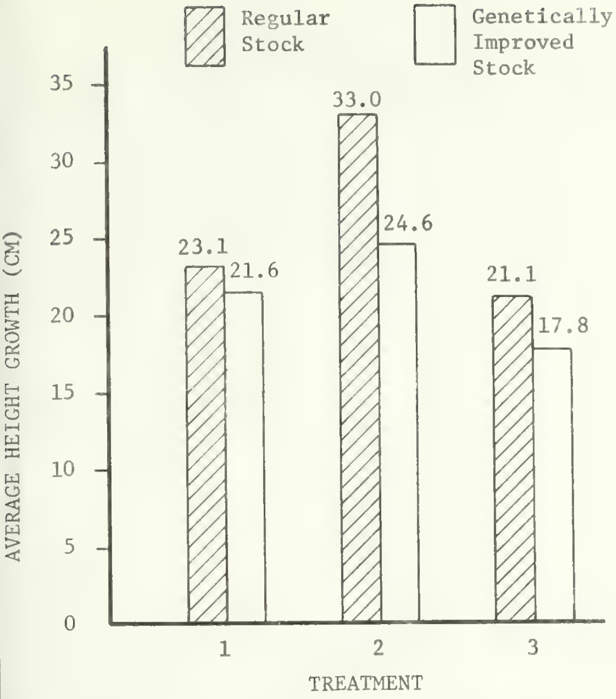
The poorer height growth in treatment 3 was possibly due to the fact that topsoil was removed or disturbed during the operations of site preparation.

Height Growth and Type of Planting Stock

Figure 2 shows a histogram of average height growths of regular and genetically improved loblolly pine seedlings planted on three differently prepared sites.

Obviously, both kinds of planting stock grew best on treatment 2, second best on treatment 1, and poorest on treatment 3. The range in average height growth was from 21.1 to 33.0 centimeters for regular seedlings and from 17.8 to 24.6 centimeters for genetically improved seedlings.

The regular seedlings on treatment 2 averaged 9.9 (42.8 percent) and 11.9 centimeters (56.4 percent) greater in average height growth than those on treatment 1 and treatment 3.



igure 2.--Average first-year height growth of regular and genetically improved loblolly pine.

eatment 1, however, produced 2.0 centimeters
.5%) more average height growth than treatment

The average height growth of genetically
nproved seedlings in treatment 2 was 3.0 centi-
ters (13.8 percent) and 6.8 centimeters (38.2
rcent) greater than that of the seedlings in
eatment 1 and treatment 3 respectively. On
eatment 1 the genetically improved trees aver-
ed 3.8 centimeters (21.3 percent) taller than
ose on treatment 3.

The regular trees on treatments 1, 2, and 3
eraged, respectively, 1.5 centimeters (6.9 per-
nt), 8.4 centimeters (34.1 percent), and 3.3
ntimeters (18.5 percent) greater in height
owth than the genetically improved trees.

Although the regular trees outgrew the
netically improved trees on every treatment, no
gnificant differences were detected between the
erage height growth of the two varieties of
blolly pine when all three site preparation
eatments were combined in the analysis.

LITERATURE CITED

trow, G., and C. Row
1976. Measuring financial gains from genetically superior trees. USDA For. Serv. Res. Pap. SO-132, 11 p.

Goddard, R. E., B. J. Zobel, and C. H. Hollis.
1975. Response of southern pines to varied nutrition. Physiological Genetics Conf. Edinburgh, Scotland, 25 p.

Haines, L. W., T. E. Maki, and S. G. Sanderford.
1975. The effect of mechanical site preparation treatments on soil productivity and tree (Pinus taeda L. and P. elliottii Engelm. var. elliottii) growth. Pages 379-395 in Forest soils and forest land management. Quebec, Canada; Les Presses de l'Universite Laval.

Hebb, A. E., and R. M. Burns.
1975. Slash pine productivity and site preparation on Florida sandhill sites. USDA For. Serv. Res. Pap. SE-135, 8 p.

Hunt, R., and G. Cleveland.
1978. Cultural treatments affect growth, volume, and survival of sweetgum, sycamore, and loblolly pine. South. J. Appl. Forestry 2(2):55-59.

Lennartz, M. R., and J. W. McMinn.
1973. Growth of two varieties of slash pine on prepared sites in south Florida: 10-year results. USDA For. Serv. Res. Pap. SE-103, 10 p.

Mann, W. F., Jr.
1974. Regeneration techniques influence subsequent stand management of young pine. USDA For. Serv. Southeast. Area State and Private Forestry.

Marlin, C. B.
1978. A study of owners of small timber tracts in Louisiana. La. State Univ. Agr. Exp. Sta. Bull. 710, 65 p.

May, J. T., S. Rahman, and R. H. Worst.
1973. Effects of site preparation and spacing on planted slash pine. J. Forestry 71:333-335.

McNab, W. H., and E. E. Ach.
1977. Slash burning increases survival and growth of planted loblolly pine in the Piedmont. USDA For. Serv. Tree Plant. Notes 28(2):22-24.

Miller, S. R.
1978. Growing our future wood supply. Pages 1-5 in Proceedings of a symposium on principles of maintaining productivity on prepared sites. USDA For. Serv. Southeast. Area State and Private Forestry.

Moehring, R. E.
1977. Final harvesting, site preparation and regeneration. Pages 99-114 in Timber Harvesting Report No. 3, Proc. 2nd Ann. Seminar for Forestry Professors. L.S.U./M.S.U. Logging and Forestry Center.

Schultz, R. P.
1975. Intensive culture of southern pines: maximum yields on short rotations. Iowa State J. Res. 49(3):325-337.

Sundra, H. J., and G. L. Lowry.
1975. Regeneration costs in loblolly pine management by seed-tree shelterwood, and planting methods. J. Forestry 73:406-409.

Wells, C. G., and D. M. Crutchfield.
1974. Intensive culture of young loblolly pine. Pages 212-228 in Proceedings symposium on management of young pines. USDA For. Serv. Southeast. Area State and Private Forestry.

EFFECT OF MECHANICAL SITE PREPARATION TREATMENTS ON HEIGHT GROWTH OF LOBLOLLY PINE IN EAST TEXAS SANDY SOILS[1]

Steven J. Arbour and Andrew W. Ezell[2]

Abstract.--The effect of using chop/burn versus shear/windrow/burn site preparation in the sandy soils of East Texas was evaluated by comparing total tree heights of ten-year-old loblolly pine (Pinus taeda L.) plantations. Stem analysis was completed on 120 trees to reconstruct height growth patterns. Results from the study indicate that trees performed better on sites receiving a chop/burn treatment when the overall site/treatment interaction is considered.

INTRODUCTION

In view of the concurrent trends of increasing demand for forest products and decreasing availability of commercial forest land, forest land managers are confronted with the prospect of producing more on less land. The obvious solution to this problem resides in increased intensive management of forest lands. In the South, this directive often leads to intensive cultural manipulation of even-aged stands of pine created by harvest-regeneration activity involving clearcutting and planting.

Following harvest operations, the first problem to be resolved in intensive pine management is the disposition of undesirable debris and residual vegetation. There are approximately 138 million acres in the South classed as southern pine sites. Of this total, alomost 73 million acres support varying amounts of unwanted hardwoods, and recent estimates indicated nearly 0.8 cubic feet of hardwoods for every cubic foot of pine on these sites (Murphy and Knight 1974).

To alleviate the problem of debris and residual vegetation, site preparation activities are usually undertaken and may be either mechanical treatments, chemical applications, burning or some combination of the three. Mechanical treatments (usually in conjunction with fire) are the prevalant form of site preparation activities in Texas, accounting for an estimated 70 per cent of the annual site preparation acreage (Blackburn et al. 1978).

Chopping and shearing are two mechanical treatments commonly employed on the sandy soils of the Coastal Plain region of East Texas. Chopping with burning is the preferred method on these sandy soils since it reduces unwanted vegetation with less soil disturbance (Balmer and Little 1978, Balmer et al. 1976, Grelen 1959).

Shearing and windrowing is very effective in concentrating debris and residuals but may result in scalping the soil surface. This site preparation method is used extensively on coarse-textured soils even though it may displace an appreciable amount of topsoil and possibly reduce site productivity (Burns and Hebb 1972, Brendemuehl 1967, Haines et al. 1973).

Quantitative information relating tree hei growth performance to chopping or shearing is lacking for East Texas. Such information is valuable to land managers in deciding which method or combination of methods has a more favorable effect on yield. Therefore, it is the purpose of this paper to examine height growth o loblolly pine in relation to mechanical site preparation treatments conducted on the sandy soils of East Texas.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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The research was completed while Mr. Arbour was a graduate research assistant at Texas A&M University, College Station, TX 77843.

MATERIALS AND METHODS

Ten-year-old loblolly pine plantations lo-ated within the Willis Geologic formation of the pper Coastal Plain region were used as sample tes in this study. Selection of plantations as according to the following criteria: (1) antations to be ten years of age, (2) planting ock of similar grade, (3) survival rate of at east 60 per cent, (4) no severe evidence of re, insect, or disease damage, and (5) plant-ion received its site preparation treatment ring summer or fall of 1969.

Plantations chosen had received either op/burn or shear/windrow/burn site preparation, d all had been machine planted during the 69-70 planting season. A total of four plan-tions (hereafter referred to as locations) were lected.

For the study, a total of twenty (20), two-re study sites were delineated. Each site was rked as a square block with sides 295 feet ng. Within each study site, three (3) circular 20-acre sample plots were established, result-g in a total of 60 sample plots for the study. l planted trees within each sample plot were mbered with aluminum tree tags to facilitate ta collection and future identification.

In addition to other data collected fro h plot, two trees were selected for stem lysis to evaluate height growth. Trees with essive crook, sweep, or forked growth were not sidered for selection and total of 120 trees e felled for stem analysis data. Discs, roximately one inch wide were removed at four-t intervals starting at the base of the tree proceeding to the top. All sample discs were ged to ensure proper identification.

The annual height growth pattern for each e was reconstructed using the method de-loped by Curtis (1964). Lenhardt's (1974) justment technique was employed to correct for wth peaks located between sample discs. From data collected, annual total height and mean ual increment were determined.

RESULTS AND DISCUSSION

Evaluation of height growth between chop/ n and shear/windrow/burn site preparation atments discloses that average total tree ght is higher on sites receiving a chop and n site preparation treatment (Table 1.). es growing on the chop and burn areas raged 7 per cent taller in total height than es found on shear, windrow and burn sites. ever, treatment effect accounts for only part the variation associated with height diffe-ces. The stratified/nested sampling design used in the study requires an analysis of treatment/location interaction to account for height differences between treatments and among locations.

Table 1. Average Annual Tree Height by Treatment and Location

Tree	Chop/Burn		Shear/Windrow/Burn	
Age	Plantation 1	Plantation 2	Plantation 3	Plantation 4
-yrs-	-----ft------	-----ft-----	-----ft-----	------ft-----
1	2.0	1.6	1.4	1.6
2	5.4	4.6	3.8	5.0
3	10.2	8.1	8.1	9.3
4	14.6	11.6	12.2	13.5
5	19.2	14.6	16.2	16.6
6	23.6	18.8	20.1	20.1
7	27.3	23.3	24.4	23.0
8	31.0	26.6	27.8	26.1
9	34.4	29.3	30.8	28.9
10	37.3	32.2	33.3	31.4
11	40.1	35.1	35.8	33.9

Height differences which may be attributed to the treatment/site interactions are analyzed in Table 2. Results of the test indicate that average total tree heights differ among locations at the $P < .01$ level.

Table 2. Analysis of variance on the effect of treatment and location on tree height.

Source	df	ss	ms	f
Location x Treatment	3	121.87	40.62	9.74**
Variation Within (Loc. x Trt.)	16	66.72	4.17	
Total	19	188.59		

**significant at $P <.01$

Average annual total height trends associated with each location are found in Figure 1. The average height of trees growing on Location 1 was 12.5%, 10.7%, and 15.5% greater than trees on Locations 2, 3, and 4, respectively. It should be noted that trees growing at Location 1 maintained height dominance over the other locations throughout all ten growing seasons.

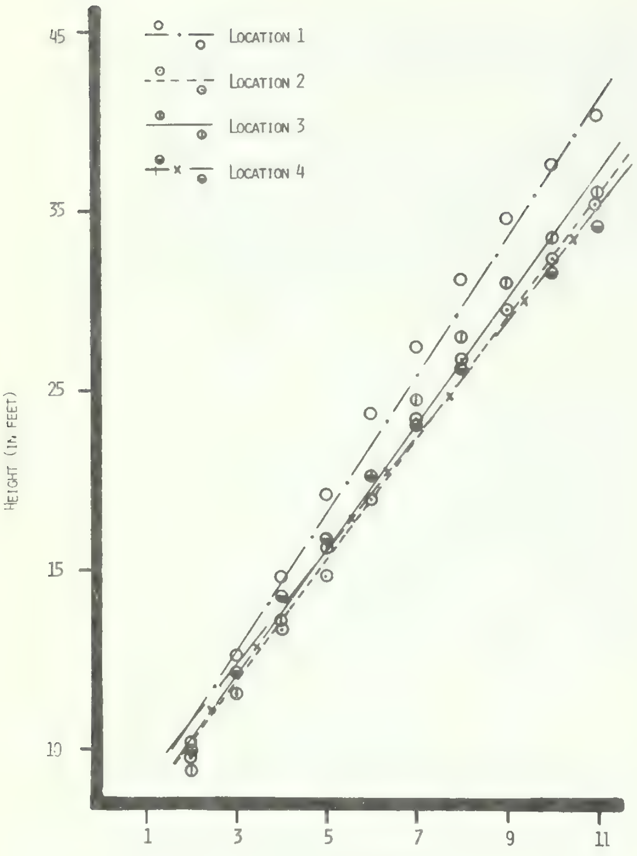

Figure 1. Average annual total height for all locations

Trees on Locations 2, 3, and 4 share a closer trend in height growth. Trees on Location 4 exhibited greater height growth than trees on Location 2 and 3 during the first four growing seasons. At this point, average tree height on Location 3 surpassed that found on Location 4 and remained greater through the tenth growing season. Average tree height on Location 2 surpassed that found on Location 4 after the seventh growing season. This variation in height dominance among the locations suggests a change in the overall capacity of the planted trees for utilizing the resources of the site and that site potential is being reflected in height growth during the later years examined in this study.

Since we are dealing with a cultural treatment applied to a physical site, consideration must be given not only to the two variables but to the site/treatment interaction as well. Variation in height growth patterns found among the locations may be due to a response to site preparation activities, differences in soil properties, or products arising from the interaction such as vegetative competition levels.

While it is beyond the scope of this paper to fully examine the effect of physical site properties, various soil parameters were measured and evaluated. Overall, Locations 1 and 2 are comparable in soil physical properties, and Locations 3 and 4 were quite similar in their measured soil characteristics. Thus, height differences due to site preparation effects may be examined within comparable soil regimes.

The greater soil depths to the least permeable horizon found at Locations 1 and 2 offer an increased volume of soil available for root penetration. Pentration and extension of root systems is a critical factor in tree growth on sandy soils The significant differences in average total height observed between Locations 1 and 2 may be attributed to other site variable-i.e. nutrient pool (as evidenced by the density of vegetation supported by two sites), soil moisture regime, or orographic differences.

By comparison, soils found at Locations 3 and 4 were considerably shallower and of finer texture than the soils at Locations 1 and 2. Root development was probably more variable and of lesser extent on these shallower sites. As was the case with Location 1 and 2, variation in height between Locations 3 and 4 was due to other inherent site properties.

In relating height growth patterns to soil physical properties, it appears plausible that trees on Location 4 encountered adverse root development conditions around age 4 due to the shallower, finer-textured soils. Height growth was restricted on Location 3 during the initial establishment period, but accelerated after the trees adapted to local site conditions. The trees on Location 2 encountered fewer impediments to root development, and although repressed in the early years, were able to better utilize the sites resources in the later years of growth examined.

In order to examine variation in height growth patterns for all locations, the annual per cent differences in tree height were evaluated (Figure 2). Location 1, the best site in terms of height growth, was used as a base, and all other locations were compared to values from that site. This comparison reveals a leveling trend in height differences past the sixth growing season. Height differences peaked at year four between trees of Locations 1 and 2.

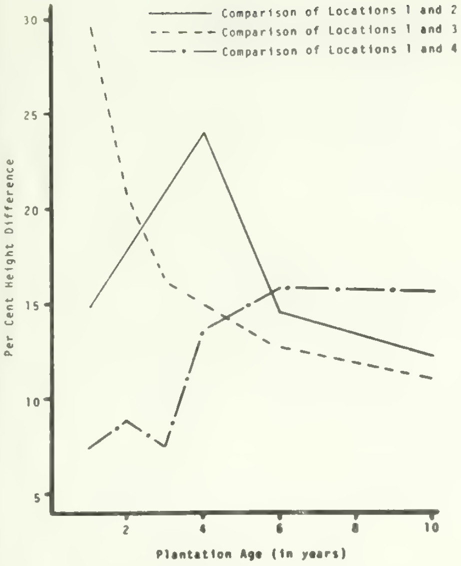

Figure 2. Comparison of differences in average annual total height for all locations.

ight trend between Locations 1 and 3 follow a fferent path, with per cent height differences clining until the sixth growing season, where- ter, the per cent differneces level out. The eatest differences in height growth patterns isted between Locations 1 and 4. Per cent ight differences peak at year six, with tree ights maintaining a uniform difference in owth rates through year ten. Again, in each of above comparisons, height dominance seems to expressed by the sixth growing season, with fferences in per cent tree height leveling out d being maintained through the tenth growing ason.

The results obtained from the study indicate at height growth was better on sites receiving chop/burn site preparation treatment. Though fferences in soil properties exist among the cations, the study was geared to evaluate chanical site preparation activities employed the sandhill region of East Texas. Since ch location received soil scarification during e planting operation, it would seem best to plement a chop/burn site preparation treatment order to incorporate and conserve available trients on the site. Implementing shear and ndrow practices could possibly give a double-arification effect to the site, augmenting moval of the nutrient-enriched top soil in ese sandy soils and, also, exposing more the soil to temperature extremes and erosive rces. These sandy soils represent an extreme the total spectrum of forest sites found in st Texas, and the impact of site preparation tivities during the critical early years of antation establishment may be more pronounced these sites. Thus, proper selection have bstantial effects on the height growth of anted trees in these areas.

LITERATURE CITED

Balmer, W. E. and N. G. Little.
1978. Site preparation methods. In Proceedings: A Symposium on Principles of Maintaining Productivity on Prepared Sites. Miss. State Univ. Starkville, p. 60-64.

Balmer, W. E., H. L. Williston, G. E. Dissmeyer, and C. Pierce.
1976. Techniques and advantages of site preparation in reforestation. Forest Farmer 36: 9-10, 35-39.

Blackburn, W. H., C. A. Hickman, J. E. deSteiguer, B. D. Jackson, T. A. Blume, and M. G. DeHaven.
1978. Silvicultural activities in relation to water quality in Texas: an assessment of potential problems and solutions. Texas Water Resources Institute Technical Report No. 97. 266 p.

Brendemuehl, R. H.
1967. Loss of topsoil slows slash pine seedling growth in Florida sandhills. USDA For. Serv. Res. Note SO-53. 4 p.

Burns, R. M. and E. A. Hebb.
1972. Site preparation and reforestation of droughty, acid sands. USDA Agric. Hndbk. 426. 61 p.

Curtis, R. O.
1964. A stem analysis approach to site index curves. For. Sci. 10:241-256.

Grelen, H. E.
1959. Mechanical preparation of pine planting sites in Florida sandhills. Weeds 7: 184-188.

Haines, L. W., T. E. Maki, and S. G. Sanderford.
1973. The effect of mechanical site preparation treatments on soil productivity and tree (Pinus taeda L. and P. elliottii Engelm. var. elliottii) growth. In Forest Soils and Forest Land Mgt. Proceedings of the 4th N. Amc. Forest Soils Conf. Laval Univ. p. 379-395.

Lenhardt, J. D.
1974. Improving height/age data from stem analysis. Texas J. of Science. Vol 25:88-89.

Murphy, P. A. and H. A. Knight.
1974. Hardwood resources on southern pine sites. Forest Prod. J. 24(7): 13-16.

THINNING AND FERTILIZATION OF LOBLOLLY PINE PLANTATIONS[1]

R. Ballard, H. W. Duzan, Jr. and M. B. Kane[2]

Abstract.--Gross volume response to nitrogen fertilization in 12 loblolly pine plantations averaged 197 and 157 cu.ft/acre over a 4-year period for thinned and unthinned areas, respectively. When assessed in terms of net volume, sawlog volume and mean diameter the relative fertilizer response advantage in thinned stands was more pronounced and consistent than for gross volume. Periodic volume response to both thinning and fertilization is modelled in terms of stand and site variables.

INTRODUCTION

Thinning and nitrogen fertilization of loblolly pine are increasingly being looked to as means of increasing yields and reducing the time for trees to grow to merchantable sizes. In addition to the opportunities provided by these silvicultural practices for alleviating supply problems created by an imbalance in age and size classes (Zobel 1980), thinning in particular is gaining in popularity for generating cash flow on small private ownerships and as a cultural practice designed to reduce the risk of southern pine beetle damage (Ku, et al 1980).

The evaluation of management alternatives and the prescription of economically and silviculturally sound management practices requires the availability of models which accurately predict the effect of various management regimes on yield for a range of conditions. The development of such models, particularly for thinning and fertilization effects, has been hindered by a lack of suitable data sets for constructing or validating such models and a limited understanding of variables influencing tree and stand response to management practices.

This paper presents some preliminary results from a series of thinning x N fertilization studies installed in loblolly pine plantations by Forest Industry Cooperators of the North Carolina State Forest Fertilization Cooperative (NCSFFC). Becaus of the preliminary nature of the data they are examined more with the intent of improving our understanding of the nature of the response to thinning and fertilization rather than for construction of predictive models.

METHODS

Trial Description

The basic study consists of a 2 x 2 factoria of thinning (+ -) and N fertilization (+ -) arran in a randomized block design. The treatments wer replicated four times at each site. The same bas study was installed at 19 separate sites. The 12 studies for which we have 4-year measurements are reported in this paper. The site and stand characteristics at time of study establishment at eac of these 12 sites are given in table 1.

The thinning prescription was to reduce the basal area (sq.ft/acre) to the numerical equivale of the estimated fifty-year site index by selecti thinning from below. While the thinning prescrip tion was consistent within sites, it was rather loosely interpreted by most cooperators giving a range of thinning intensities over sites (table

Nitrogen fertilizer was applied in early sp as ammonium nitrate at the rate of 150 lbs N/acr On sites where P or K deficiencies were suspecte on the basis of soil and foliar analysis, fertil applications of these elements were made to all plots.

Measurements

Diameter at breast height and heights of al or a sample of trees across the diameter range ble 1.--Initial site and stand characteristics

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Age	Site index 2/	Stems per acre 3/		Basal area		Mean diameter	
		UT	T	UT	T	UT	T
(yr)	(ft)			--(sq.ft/ac)--		----(in)-----	
16	61	555	311	131	92	6.4	7.3
18	62	601	402	145	120	6.5	7.2
14	60	619	409	97	80	5.1	5.8
11	79	540	285	150	99	7.0	7.9
17	58	680	308	164	103	6.5	7.8
21	67	568	250	173	91	7.3	8.1
15	72	600	254	179	92	7.3	8.1
14	64	713	319	166	100	6.4	7.5
12	76	762	415	191	116	6.7	7.1
20	66	446	208	158	83	7.9	8.1
20	56	470	248	161	101	7.9	8.6
15	62	717	303	151	84	6.1	7.1

1/ NCSFFC Study code.
2/ 25 year base
3/ Unthinned (UT), thinned (T)

re recorded at the initiation of the trials and ain after four growing seasons. Heights for all ees in each plot were estimated from height-ameter equations developed for each treatment.

Total individual tree stem volumes (o.b.) were lculated using the volume equation of Smalley and wer (1968). Net periodic volume increment was tained by taking the difference between estimates per acre living volume at trial initiation and at after four growing seasons. Gross periodic lume increment was obtained in a similar manner cept trees which died during the 4-year assess-nt period were included in the estimate of the lume at the end of the assessment period. Sawlog lumes were calculated using the equation of rkhart *et al*. (1972).

atistical Analysis

Estimates of volume and diameter increments er the 4-year measurement period were adjusted initial differences in these variables using variance analysis. The covariance adjustment was he *within* thinning treatment as it would otherwise nove thinning effects since the covariate is iated to thinning.

RESULTS AND DISCUSSION

inning Response (unfertilized stands)

Thinning in unfertilized stands reduced 4-year oss volume increments an average of 322 cu.ft/acre 1.8%) over that in unthinned plots (table 2). wever, as a result of a lower mortality in thinned ots, the average reduction was only 9.6% for net lume increment and 5 out of 12 trials even showed gain in net volume production in the thinned rela-ve to the unthinned treatments.

As expected, mean diameter increment in thinned stands was greater than that in unthinned stands due to concentration of growth on fewer stems. Despite this concentration of growth on fewer, larger stems in thinned stands, sawlog volume increment was on average still greater in unthinned stands. Undoubtedly most of the volume increment in the unthinned stands was put onto dominant and codominant stems; the lack of growth on small suppressed trees would act to reduce the average diameter increment in unthinned stands.

The trends noted above are not unusual or new (Feducia and Mann 1976). They are also obtained over a relatively short growth period and since thinning effects tend to be long-term in nature, they must be regarded only as early trends.

Growth in Thinned Stands (unfertilized)

To gain an insight into factors influencing growth of thinned stands, two approaches are available: develop an independent model of growth for thinned stands or examine deviation in growth in thinned stands from those predicted using a standard growth model for unthinned stands. We chose the latter approach because of the availability of an independent model for predicting periodic volume increment of loblolly pine stands and the general acceptance of the philosophy of this approach in modelling management effects on forest yields (Pienaar 1979; Reukema and Bruce 1977).

The independent model relating 5-year gross volume increment (PV5) to basal area (BA) and 25-year site index (SI) was developed with data from 79 NCSFFC study sites representing close to the complete ranges of site and stand conditions found in unthinned, unfertilized loblolly pine plantations in the South:

$$PV5 = (9.7 + BA)/(0.046 - 0.0004*SI + 0.0008*BA - 0.000005*BA*SI)$$

$$R^2 = 0.66 \qquad Sx.y = 287$$

Using this model PV5 was predicted for each of the 12 thinned and unthinned stands. To enable comparison with the observed 4-year gross volume increment, predicted PV5 was proportionally adjusted using a factor of 0.8. Deviations between observed and predicted values were calculated as were the standard deviations of these residuals for each type of stand:

	4-yr gross volume increment			
Stand	Mean Observed	Predicted	Residual	Sx.y Residual
	--------(cu.ft/acre)---------			
Unthinned	1478	1427	25	268
Thinned	1156	1319	-188	313

There is a good prediction of volume increment in the 12 unthinned stands with a close correspondence of Sx.y values for the independent model using the original 79 sites and the 12 current study, Table 2.--Four-year volume and diameter increments for unthinned (UT) and thinned (T) stands

Study No.	Gross volume			Net volume			Sawlog volume			Mean diameter 1/	
	UT	T	(UT-T)	UT	T	(UT-T)	UT	T	(UT-T)	UT	T
	(cu.ft/ac)						(bd.ft/ac)			(in)	
2	1132	1044	*88*	733	1042	*-309*	3532	3691	*-159*	0.72	0.87
9	1599	1713	*-114*	1428	1623	*-195*	5930	6432	*-502*	0.64	0.88
11/1 2/	1492	1359	*133*	1392	1298	*94*	3678	3390	*288*	0.89	1.00
11/2	1742	1305	*437*	1729	1305	*424*	6131	4873	*1258*	0.60	0.83
14	1070	914	*156*	862	886	*-24*	3410	3531	*-121*	0.41	0.74
15/1	1215	787	*428*	580	739	*-159*	4675	3068	*1607*	0.38	0.59
15/2	1483	753	*730*	885	379	*506*	5310	2444	*2866*	0.39	0.60
15/3	1690	1383	*307*	1505	1265	*240*	5421	5195	*226*	0.63	1.22
16	1936	1349	*587*	1498	1300	*198*	6888	4829	*2059*	0.57	0.80
22/1	1208	894	*314*	750	793	*-43*	4426	3231	*1195*	0.51	0.84
22/5	1224	904	*320*	1122	904	*218*	4547	3758	*789*	0.60	0.73
23	1947	1471	*476*	1880	1445	*435*	4998	5306	*-308*	0.74	1.39
Avg.	1478	1156	*322*	1197	1082	*115*	4912	4144	*768*	0.59	0.87

1/ Mean increment on trees surviving at the final measurement.
2/ Five-year data.

unthinned sites. This provides confidence that the large deviation between observed and predicted values for thinned stands, shown above, is a real effect of thinning and not the result of the 12 sites representing a different population from that used to construct the independent model.

Our data above show that volume growth in thinned stands is, on average, well below that in unthinned stands of the same basal area and site index. We hypothesized that deviations from predictions using unthinned stands might be associated with effects of thinning on 1) the crown/basal area ratio, 2) the diameter distribution, and 3) damage to the soil and residual trees. A number of variables, with potential as indicators of effects 1) and 2) were screened for their ability to explain variation in the deviations from predicted volume increment (RES. V). We had no measure of thinning "damage" for the various sites. Variables screened included:

$$\text{Relative basal area reduction (BAR)} = \frac{\text{BAU} - \text{BAT}}{\text{BAU}},$$

Where BAU = basal area for unthinned stand
BAT = basal area for thinned stand,

$$\text{Index of selectivity (IS)} = \frac{\log\ (\text{BAR})}{\log\ (\text{SPAU-SPAT/SPAU})},$$

Where SPAU = stems/ac for unthinned stands
SPAT = stems/ac for thinned stands
(note, the more selective the thinning is for size-low thinning-the larger IS becomes-Pienaar 1979),

and also BAU, BAT, SPAU, SPAT, BAU*SPAU and SI.

The best single, double and triple variable prediction equations developed, after looking at all variable combinations, are shown below:

1. $\text{RES.V} = -1765 + 1107{*}\text{IS} \quad R^2 = 0.33$
$\text{Sx.y} = 268$

—the more selective the thinning (from belo the less the reduction in volume growth relative to an unthinned stand of the same BA & SI.

2. $\text{RES.V} = -1842 + 766{*}\text{IS} + 1.82{*}\text{SPAT}$
$R^2 = 0.46$
$\text{Sx.y} = 256$

—the more selective the thinning and the larger the number of stems left after thinning, t less the reduction in volume growth relative to a unthinned stand of the same BA and SI.

3. $\text{RES.V} = -766 + 11.5\ \text{BAT} - 8.3\ \text{BAU} + 1.25\ \text{SPAU}$
$R^2 = 0.52$
$\text{Sx.y} = 253$

—the greater the basal area left after thin ning, the greater the number of stems before th ning and the lower the basal area before thinnin the less the reduction in volume growth relative to an unthinned stand of the same BA and SI.

Little effort will be made here to develop biological explanations for the above relationsh It is apparent that most of the variables are in some way related to the selectivity of thinning, the intensity of thinning, and the degree of suppression of residual tree crowns. Suffice it to say that these relationships provide an indic tion of the types of variables we should evaluat in attempting to develop definitive thinning mod A word of warning however, the relative importan different variables in predicting deviations in riodic growth of thinned stands will undoubtedly ry according to the length of the period after inning considered.

The generally low R^2 values for our "best" ediction equations indicate that we have a long y to go in developing appropriate variables to count for the effects of thinning. One effect t evaluated here, and which may account for some the unexplained variation, is the effect of damage the soil and residual trees during the thinning eration. Work is needed on this important estion.

rtilizer Response

Volume and diameter responses to fertilization re significant in 9 out of the 12 trials. The gnitude and frequency of the response to N ferlizer is consistent with the findings of NCSFFC om a large number of other trials in loblolly pine antations (Ballard 1980). Gross volume responses re, on average, greater in thinned stands, but it s not a consistent trend (Table 3). While the erage relative response gain for thinned over thinned stands was only 25% for gross volume, it s 49%, 64%, and 90% for net volume, sawlog volume, d mean diameter, respectively. The consistency of e trend also increased in the same order. Such trend is expected with the volume response in inned stands goint onto fewer, larger stems (fig. . Volume response in thinned stands thus tends to

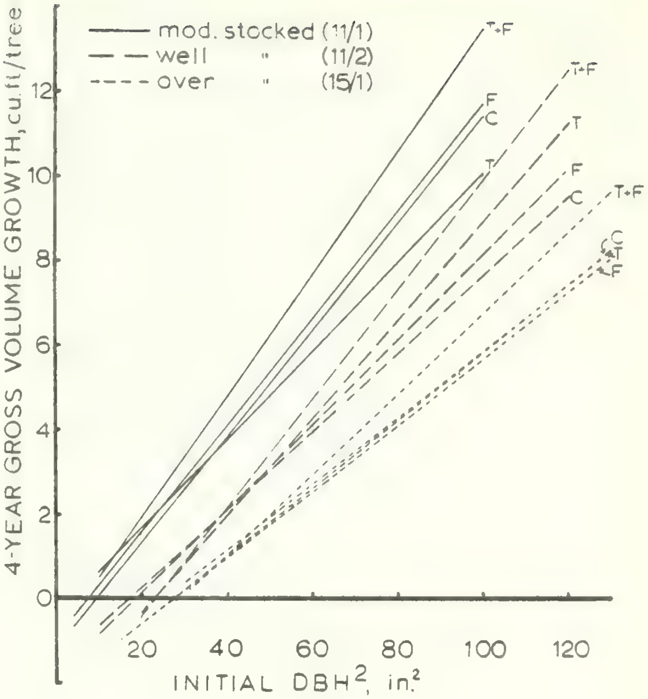

Figure 1.--The effect of thinning (T) and fertilization (F) on volume growth by initial diameter class in three loblolly pine stands of different initial stocking.

ble 3.--Four-year volume and diameter gains from N fertilization of unthinned (UT)and thinned (T) stands.

udy o.	Gross volume			Net volume			Sawlog volume			Mean diameter[1]		
	UT	T	(UT-T)	UT	T	(UT-T)	UT	T	(UT-T)	UT	T	(UT-T)
	(cu.ft/ac)						(bd.ft/ac)			(in)		
	166	2	*164*	255	-60	*310*	159	-107	*266*	0.06	0.13	*-0.07*
	173	96	*77*	45	32	*12*	43	270	*-227*	0.08	0.13	*-0.05*
1[2]	163	348	*-185*	127	385	*-258*	-149	1052	*-1201*	0.03	0.36	*-0.03*
2	-44	201	*-245*	-193	201	*-394*	-90	1073	*-1163*	0.08	0.18	*-0.10*
	404	241	*163*	373	269	*104*	1249	1019	*230*	0.13	0.16	*-0.03*
1	84	135	*-51*	84	69	*15*	109	418	*-309*	0.05	0.13	*-0.08*
2	139	313	*-174*	675	434	*241*	832	1245	*-413*	0.21	0.27	*-0.06*
3	216	199	*17*	-13	169	*-182*	350	723	*-373*	0.16	0.07	*0.09*
	103	342	*-239*	-35	345	*-380*	578	1336	*-758*	0.10	0.22	*-0.12*
1	133	107	*26*	-183	-20	*-163*	-19	393	*-413*	0.15	0.10	*0.05*
5	185	112	*73*	217	98	*119*	859	127	*732*	0.06	0.27	*-0.21*
	157	260	*-103*	135	286	*-151*	872	303	*569*	0.05	0.20	*-0.15*
v.	157	197	*-40*	124	185	*-61*	399	654	*-255*	0.10	0.19	*-0.09*

/Mean gain on trees surviving at the final measurement.
/Five-year data.

be more valuable than an equivalent response in unthinned stands.

An often heard concern about thinning is the effect it has over conventional rotation lengths, of reducing total volume yield. Our data show that fertilization can be used to offset this yield loss. Over the 4-year period from thinning, thinned and unfertilized stands produced 322 and 115 cu. ft/acre less gross and net volume, respectively, than their unthinned counterparts (table 2). Fertilization of thinned stands however increased gross and net volume production 197 and 185 cu. ft/acre, respectively (table 3). Thus thinned and fertilized stands had a greater net volume production (70 cu.ft/acre) but a still lower gross volume production (-125 cu.ft/acre) than unthinned stands over the 4-year period. Fertilization acts to speed up site reoccupancy after thinning.

Modelling Fertilizer Response

Unthinned stands -- Consistent with our findings using data from other trials (Duzan and Allen 1980) we found a simple model with basal area at time of fertilization (BA, sq.ft/acre) and site index 25 (SI, ft) gave the best prediction of 4-year gross volume response to N fertilization (ΔV, cu.ft/acre)

$$\Delta V = 736.8 + 1.55*BA - 12.6*SI \qquad R^2 = 0.63$$
$$sx.y = 68.3$$

The 12 plantations used for these studies are on non P-deficient sites with a relatively narrow range of drainage classes. Under these circumstances the SI may be reflecting site N status. Basal area, as an index of growing stock, reflects the potential of the stand to put on extra volume in response to fertilization.

Thinned stands--In addition to SI and BA a number of other variables including IS, BAR, SPA were screened alone and in various combinations for predicting gross volume response in thinned stands. The general level of prediction was very poor with only one variable (stems per acre prior to thinning, SPAU) providing a significant prediction.

$$\Delta V = -214 + 0.68*SPAU \qquad R^2 = 0.38$$
$$Sx.y = 90.1$$

The R^2 value for the equation could not be significantly improved by inclusion of any other tested variable. The biological explanation for this relationship is unclear and thus use of it for prediction purposes, even within the range of conditions encountered in the calibration population, is not recommended.

Our understanding of the mechanism of N fertilizer response in thinned stands must be improved in order to generate variables with a sound biological basis and good predictive capability. A factor which could have contributed to the poor prediction by site and stand variables is a variation between sites in degree of site disturbance during thinning. The degree of disturbance can influence both the N status of the site and the vigor of the residual trees.

It is noticeable that while the characteristic of thinning response and fertilizer response in unthinned stands are influenced by stand conditions those of response in thinned stands appear to be largely independent of them (fig. 1). Fertilizatio of thinned stands appears to stimulate volume growth in larger diameter classes to a greater extent than that in smaller diameter classes irrespective of stocking levels prior to thinning. Apparently in overstocked stands with severely suppressed individual tree crowns, N fertilization is required to rejuvenate individual tree crowns in order for the trees to respond to the additional crown space provided by thinning.

LITERATURE CITED

Ballard, R. 1980. Nitrogen fertilization of established loblolly pine stands: a flexible silvicultural technique. Paper presented at Southern Silvicultural Research Conference, Atlanta, November 6-7, 1980.

Burkhart, H.E., R.C.Parker, M.R. Strub, and R.G. Oderwald. 1972. Yields of old-field loblolly pine plantations. FWS-3-72 Div. For. Wildlif Resources, VPI and SU. Blacksburg, VA.

Duzan, H.W., Jr. and H. L. Allen. 1980. Estimating fertilizer response in site prepared lobloll pine plantations using basal area and site index. Paper presented at Southern Silvicultural Research Conference, Atlanta, November 6-7, 1980.

Feduccia, D.P. and W. F. Mann, Jr. 1976. Growth following initial thinning of loblolly pine planted on a cutover site at five spacings. USDA For. Serv. Res. Paper. SO-120. 8 p.

Ku, T.T., J.M. Sweeney and V.B. Shelbourne. 1980 Site and stand conditions associated with southern pine beetle outbreaks in Arkansas— a hazard-rating system. South. J. Appl. For. 4: 103-106.

Pienaar, L.V. 1979. An approximatinon of basal area growth after thinning based on growth in unthinned plantations. For. Sci. 25:223-232.

Reukema, D.L. and D. Bruce. 1977. Effects of thinning on yield of Douglas-fir: concepts and some estimates obtained by simulation. USDA, For. Serv. Gen. Tech. Report. PNW-58. 36 P.

Smalley, G. W. and D. R. bower. 1968. Volume tables and point-sampling factors for loblolly pine in plantations on abandoned fields in Tennessee, Alabama, and Georgia Highlands, USDA, For. Serv. Res. Paper SO-32. 13 p.

Zobel, B. J. 1980. Imbalance in the World's conifer timber supply. Tappi 63: 95-98.

INFLUENCE OF PRUNING ON WOOD GROWTH AND PRODUCT VOLUME IN A LOBLOLLY PINE PLANTATION[1]

Terry R. Clason and Charles T. Stiff[2]

Abstract.--Effects of one-and two-step pruning on tree growth were studied. At age 6, a precommercial thinning and a pruning to 1/2 total tree height were applied singularly or in combination. Five years later, plots treated initially were thinned to 100, 200, or 300 trees per acre and residual trees pruned to 17 feet. On plots thinned to 100 trees per acre, trees pruned at age 6 but not thinned were significantly smaller than either of the precommercially thinned one-or two-step prunings. Two-step pruning, applied with a precommercial thinning, did not reduce tree growth.

INTRODUCTION

On a given site, loblolly pine stands of milar age and composition will produce the me total stem cubic-foot volume over a range stocking densities. However, how the wood eld is distributed among products on indivi- al trees will influence the stand's ultimate lue. Quite often, higher value can be attained growing a small number of large diameter trees itable for lumber and plywood. Various silvi- ltural practices can be used to manipulate and composition and density to yield high- ality crop trees in the shortest possible time.

Practices such as site preparation, arti- cial regeneration, hardwood brush control, and rly and frequent thinnings are extremely bene- cial to the rapid growth of high-value pine antations. Pruning, which enhances formation knot-free wood, could contribute significantly the development of premium sawtimber trees. en used in conjunction with other high-yield lvicultural practices, such as thinning, uning schedules can be developed to maximize ot-free wood formation. This report discusses e effect of one-and two-step pruning schedules sawtimber production and quality in a 29-year- d loblolly pine (*Pinus taeda L.*) plantation.

MATERIAL AND METHODS

Data

Data were collected from a 29-year-old loblolly pine plantation located on the North Louisiana Hill Farm Experiment Station near Homer, Louisiana. Research plots were established on an abandoned cotton field with soil types mainly from the Shubuta, Luverne and Bowie Series, all having a fine sandy loam texture. Site index averaged 68 feet on a 25-year base, with site quality of individual plots ranging from 65 to 78 feet.

In February 1950, bare rooted seedlings, graded as 1 and 2 by Wakeley's (1954) grading system, were planted on the 10-acre study area. Seedlings were grown from loblolly seed collected by the Louisiana Forestry Commission from natural stands located in North Louisiana. Prior to planting, site preparation included cutting existing pine and hardwood saplings, poisoning stumps and burning.

Within the study area two 1-acre blocks each were planted at 4x4, 6x6, 6x8, 8x8, and 10x10-foot spacings. Survival rates were generally high but interplanting was done where necessary. Hardwood competition and pine mortality on one 10x10-foot block necessitated its exclusion from the study.

In 1955 at age 6, each block was sub-divided into 4 plots. Measurement areas ranged from 0.16 to 0.29 acres without buffer strips. Three cultural treatments were randomly assigned to each block:

1. Precommercially thin (PCT) to 400 trees per acre (TPA);

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2. Prune (PRN) 400 crop TPA to 8 feet or 1/2 total height;

3. Precommercially thin to 400 TPA and prune to 8 feet or 1/2 total height (PCT x PRN).

The fourth plot in each block was maintained untreated as part of the original spacing study. From 1955 to 1960, diameter and height were measured annually on crop trees only. Subsequent data analyses were done assuming no treatment effect from initial spacing treatments.

Five years later at age 11, three commercial thinning treatments were applied to the previously treated plots. Treatments included:

1. Thin to 100 TPA (T100) and prune to 17 feet;

2. Thin to 200 TPA (T200) and prune to 17 feet;

3. Thin to 300 TPA (T300) and prune to 17 feet.

The 1960 treatments were replicated three times on each 1955 treatment and growth data were collected on a periodic basis from 1960 through 1978. Resulting age 6 and age 11 treatment combinations summarized in Table 1 provide a comparison between one-and two-step pruning schedules.

Table 1.--Treatment designations for age 6 and 11 treatment combinations[1]

Age 6 Treatments	Age 11 Treatments T100	T200	T300
PCT	TRT11	TRT12	TRT13
PRN	TRT21	TRT22	TRT23
PCT x PRN	TRT31	TRT32	TRT33

[1] TRT11, TRT12, and TRT13 specify one-step pruning schedules, while other combinations indicate two-step prunings.

Times required to apply the 1955 and 1960 treatments were recorded. Precommercial thinning was accomplished with a hand bow saw at the rate of 60 trees per hour. Pruning, which was done with a pole pruning saw, averaged 12.5 trees per hour in 1955 and 6.6 trees per hour in 1960. The average times required per tree for each pruning schedule were 9.1 minutes for a one-step and 13.9 minutes for a two-step schedule. Pulpwood volumes removed during the 1960 thinning at age 11 were 10.3, 6.7, and 5.1 cords for 100, 200 and 300 TPA plots, respectively.

Taper data were collected on 454 felled trees in 1978 at age 29. Individual tree volumes, both inside and outside bark, were accumulated from a 6-inch stump to the tree top. In addition, analytically derived individual tree cubic-foot product volumes were computed under the following assumed merchantability standards:

1. Butt bolt - cubic feet in the first 8.3-foot sawlog;
2. Butt log - cubic feet in the first 16.7-foot sawlog;
3. Sawlogs - top dib $\geq$ 8 inches;
4. Chip-n -sawlog - 6 inches $\leq$ top dib $<$ 8 inches
5. Chips - 3 inches $\leq$ top dib $<$ 6 inches;
6. Top - top dib $<$ 3 inches.

In this way, individual tree product mix was maximized. Volumes were calculated for 2-foot 1-inch sections via the following conic formula:

$$V_i = 0.0021513847 \{ D_i^2 + d_i^2 + D_i d_i L_i \} \qquad (1)$$

where,

V_i = cubic-foot volume of the ith conic section, $i = 1, 2, \ldots, m$;
D_i = diameter (inches) of the large end of the ith section;
d_i = diameter (inches) of the small end of the ith section;
L_i = length (feet) of the ith section.

Analysis

Analysis of covariance (ANOCOV) was utilized to test for treatment interaction differences in plot attributes by the following linear model:

$$W_{ijk} = \mu + (\alpha\beta)_{ij} + \gamma X_{ijk} + \varepsilon_{ijk} \qquad (2)$$

where,

W_{ijk} = value of the plot attribute for the ith treatment 1955, $i = 1, 2, 3$; and the jth treatment 1960, $j = 1, 2, 3$; and kth observation, $k = 1, 2, \ldots l_{ij}$;
μ = true mean of the population;
$(\alpha\beta)_{ij}$ = the interaction between ith treatment 1955 and jth treatment 1960;
γX_{ijk} = regression of W_{ijk} on X_{ijk}, where X_{ijk} = site index;
ε_{ijk} = error component.

Site index was used as a covariate to adjust for site quality differences in the comparisons.

Data were also analyzed to determine effect of pruning on total merchantable volume, total sawlog volume, and butt bolt and butt log volume. Treatment effects were tested by ANOCOV with the following linear model:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \gamma X_{ijk} + \varepsilon_{ijk} \qquad (3)$$

ere,

Y_{ijk} = individual tree cubic-foot volume for the ith treatment 1955, i = 1, 2, 3; the jth treatment 1960, j = 1, 2, 3; and the kth observation, k = 1, 2, ..., n_{ij};

μ = true mean of the population;

α_i = the effect from the ith treatment 1955;

β_j = the effect from the jth treatment 1960;

$\alpha\beta)_{ij}$ = the interaction between the ith treatment 1955 and the jth treatment 1960;

γX_{ijk} = regression of Y_{ijk} on X_{ijk}, where X_{ijk} = site index;

ε_{ijk} = error component.

ans for both plot attributes and felled trees re tested orthogonally at the α = 0.10 level.

Percent clear wood determinations were made om 90 sawn butt logs for grade "D" and better mber. Logs were 16.5 feet long and averaged .8 inches at the small end. Since individual g data were not available, differences in pernt clearwood by treatment combination were not alyzed.

RESULTS

Diameter growth on the research plots was gnificantly influenced by both thinning and uning treatments applied at age 6. Foil *et al.* 964) reported that precommercial thinning signicantly stimulated diameter growth, regardless pruning. However, pruning to 1/2 tree height erted a negative response, especially during e first three years. By age 11, thinned plot CT) diameter increment was 1.0 and 0.6 inch eater than the pruned (PRN), and the thinned l pruned plots (PCT x PRN), respectively. Detnental effects on diameter growth from pruning percent or more live crown have been substanated by other studies (Labyak and Schumacher 1954, Young and Kramer 1972, and Banks and Prevost 1976). Also, Banks and Prevost (1976) indicated that following a severe pruning adjacent unpruned trees generally grow at a faster rate and surpass the pruned trees.

The age 11 thinning treatments (T100, T200 and T300) affected individual tree diameter growth significantly. Differences in diameter growth between thinning intensities were significant at ages 14, 23, and 28 (Foil *et al.* 1964, Shepard 1974, and Sprinz *et al.* 1979). The 17-year period following thinning resulted in a 7.5, 5.6, and 4.4-inch diameter growth increment in the 100, 200 and 300 TPA plots, respectively. During this same period, growth increments on age 6 treatments did not differ and averaged 6.5 inches.

Plot Analysis

Thinning treatments applied at age 11 affected plot diameter class distribution. By age 29, relative cumulative frequency of diameters larger than 10 inches increased as thinning intensity increased (Fig. 1). More than 95 percent of tree diameters on plots thinned to 100 TPA were larger than 10 inches. The 11-inch and larger diameter classes accounted for 72 and 50 percent of the trees on 200 and 300 TPA plots, respectively.

In the analysis of age 6 and 11 treatment effects, the influence of different pruning schedules on stand growth and development were not discernible. However, comparisons between average plot diameters at age 29 by age 6 treatments within age 11 treatments (Table 1) revealed that pruning schedules have affected stand development (Table 2). Significant differences existed between the age 6 treatments thinned to 100 TPA at age 11. Average diameter on the TRT21 plots was significantly smaller than TRT11 and TRT31. No difference was detected between TRT11 and TRT31. Thus, a two-step pruning

Table 2. Average plot attributes by treatment combination for 29-year-old loblolly pine.

Plot Attribute	Treatment								
	TRT11	TRT12	TRT13	TRT21	TRT22	TRT23	TRT31	TRT32	TRT33
n	3	3	2	3	3	3	3	3	3
Dbh[1] (in.)	15.3^{a} ±0.3	11.4^{c} ±0.3	10.9^{d} ±0.4	13.7^{b} ±0.3	11.9^{c} ±0.3	10.3^{d} ±0.3	15.0^{a} ±0.3	11.6^{c} ±0.3	10.3^{d} ±0.3
Height (ft.)	75.6 ±4.7	74.3 ±4.2	70.9 ±0.1	74.2 ±2.9	71.6 ±2.6	72.8 ±7.7	71.6 ±2.2	73.8 ±0.8	71.9 ±4.6
Site Index (ft.)	70.5 ±3.3	70.6 ±4.4	67.2 ±1.6	69.1 ±2.3	66.8 ±1.0	69.6 ±7.3	67.1 ±1.5	69.0 ±1.6	70.1 ±3.2
Basal Area[1] (ft^2/acre)	117^{a} ±8	120^{a} ±8	130^{a} ±10	95^{b} ±8	127^{a} ±8	122^{a} ±8	114^{a} ±8	114^{a} ±8	127^{a} ±8
Volume o.b.[1] (ft^3/acre)	4210^{a} ±318	4291^{a} ±319	4654^{a} ±388	3408^{b} ±313	4599^{a} ±323	4454^{a} ±314	4093^{a} ±320	4120^{a} ±313	4458^{a} ±316
Volume i.b.[1] (ft^3/acre)	3320^{a} ±250	3369^{a} ±251	3651^{a} ±305	2684^{b} ±246	3615^{a} ±254	3491^{a} ±247	3228^{a} ±252	3236^{a} ±246	3493^{a} ±248

[1] Least square means: means with the same letter for each response variable do not differ significantly at the α = 0.10 level.

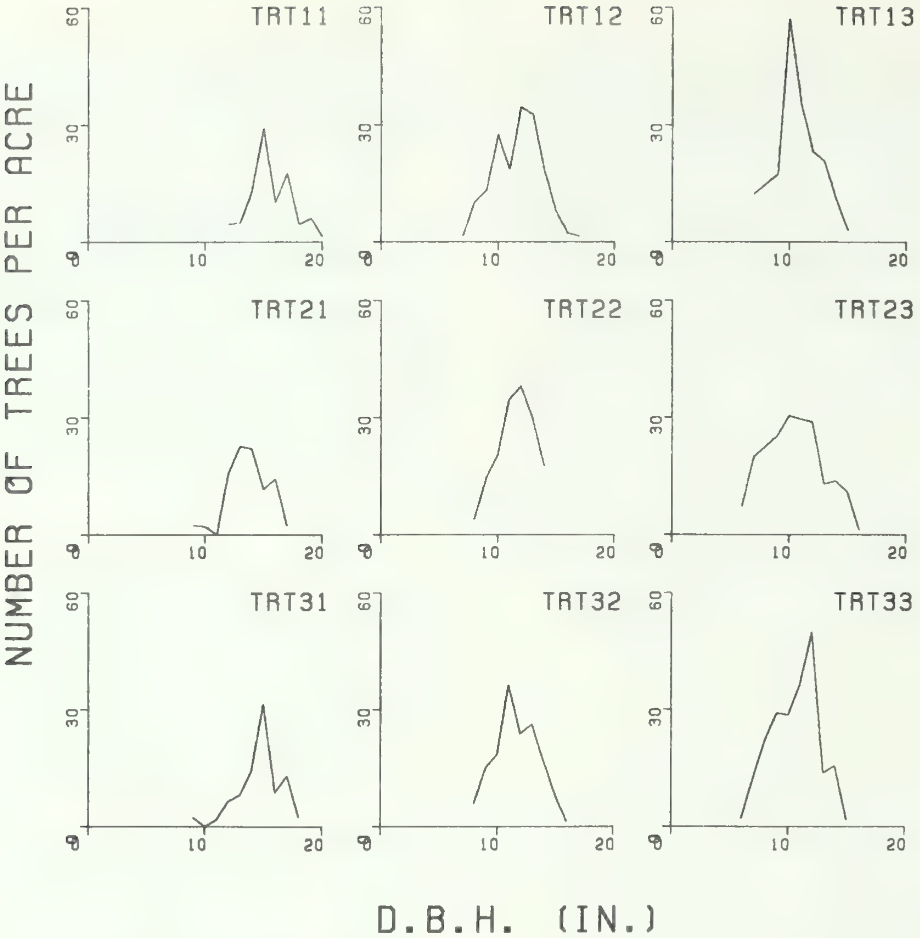

Figure 1. Diameter class distributions by treatment combinations prior to 1978 thinning for 29-year-old loblolly pine.

schedule, applied in conjunction with a precommercial thinning, followed by a subsequent stocking reduction to 100 TPA, did not reduce average stand diameter any more than a one-step pruning. However, pruning without precommercial thinning resulted in reduced diameter growth.

Similar comparisons for 200 and 300 TPA plots indicated nonsignificant differences (Table 2). Apparently, individual tree competition on the 200 and 300 TPA plots was such that the growth advantage manifested at age 11 on PCT plots was lost by age 29.

Basal area and volume decreased as stand density decreased (Table 2). Except for TRT21, differences between combinations were nonsignificant.

Bennett (1955) stated the advantage of two-step over one-step pruning was a greater production of clear wood. Percent clear wood in the butt sawlogs in Table 3 support that contention. However, as stated previously, individual log observations were unavailable for analyzing treatment differences. Both two-step pruning schedules yielded 50 to 100 percent more clear wood than the one-step.

Table 3. Percent clear wood by treatment combination for 29-year-old loblolly pine.

Treatment	Number logs	Average diameter (Inches)	Average log volume (ft^3)	Percent clear wood
TRT11	19	11.5	14.5	14.6
TRT12	8	10.8	12.4	17.5
TRT13	8	10.6	12.3	3.9
TRT21	14	11.1	13.4	28.8
TRT22	7	10.8	11.7	24.0
TRT23	10	11.0	12.9	24.0
TRT31	13	10.5	12.7	24.3
TRT32	8	10.8	12.0	22.3
TRT33	4	10.1	10.7	12.9

Table 4. Diameter class distributions of 454 felled trees by treatment combination for 29-year-old loblolly pine.

Treatment	Diameter Class (inches)														Total	Ave. Dbh (in.)
	6	7	8	9	10	11	12	13	14	15	16	17	18	19		
	number of trees															
TRT11							2	2	2	7	5	3	1	1	23	14.86 ±0.41
TRT12		1	4	8	11	8	10	10	3	3	1				59	10.87 ±0.25
TRT13		4	5	7	18	8	5	3	1	1					57	10.35 ±0.27
TRT21				1	1	0	4	5	7	5	4				27	13.46 ±0.37
TRT22			2	7	9	12	11	8	3	0	1				53	11.32 ±0.23
TRT23	3	11	12	11	15	13	9	3	6	4					87	9.86 ±0.21
TRT31				1	0	0	2	1	4	5	0	2	1		16	14.34 ±0.47
TRT32			3	10	12	17	8	9	4	2					65	11.10 ±0.24
TRT33	1	6	10	12	11	11	13	4	4						72	9.86 ±0.23
TOTAL	4	22	36	57	77	69	64	45	34	27	11	5	2	1	454	

dividual Tree Stem Analysis

Diameter class distributions of the 454 felled ees by treatment combination (Table 4) are simi- r to the 1978 treatment diameter distributions all trees (Fig. 1). Average d.b.h. for the lled trees was slightly less but still within standard deviations of the average plot dia- er (Tables 2 and 4). Thus, individual tree lumes from the felled trees provided a represent- ive sample for the analyses.

Table 5 shows age 6 and 11 treatment effects individual tree volumes. At age 29, significant fferences were expressed only among the age 11 eatments. Total individual tree volume and all vlog volumes increased as thinning intensity creased. The percentage of total stem volume esent in the butt sawlog was 43, 33, and 22 per- nt for the 100, 200 and 300 TPA plots, respec- vely.

TRT11, TRT21, and TRT31 were the only treat- nt combinations significantly affected by the fferent pruning schedules (Table 6). Trees re- ving a two-step pruning without a precommercial nning had significantly less total, sawlog, butt and butt bolt volumes than the precommercially nned treatments. No volume differences were ected between TRT11 and TRT31. Butt log volume counted for 42, 42, and 45 percent of the total ume for TRT11, TRT21, and TRT31, respectively.

Individual tree cubic-foot product breakdowns treatment combinations appear in Table 7. Cubic- t product volumes for total, sawlog, butt log butt bolt are essentially the same as the ad- ted volumes found in Tables 5 and 6. Volume of ser value products, chips and chip- n-sawlogs, reased as thinning intensity decreased.

DISCUSSION

Guidelines for pruning have been discussed in previous studies involving the development of premium sawtimber trees. Labyak and Schumacher (1954) suggested pruning a selected number of crop trees in fully-stocked stands accompanied by a severe thinning to preclude further natural pruning. Bennett (1955) recommended a practical schedule for pruning wider-spaced, old-field, slash pine plantations on good sites. His schedule is similar to that utilized in the present study. In addition, timing of pruning should be based on height, diameter and taper characteristics of the 100 largest trees per acre (Banks and Prevost 1976). The first pruning should be done when average tree diameter is 4.0 inches (Vel 1975). Locatelli (1977) stated pruning would be profitable, provided only crop trees are pruned and pruning is done on at least 7-acre blocks.

The present study has shown that guidelines stated above can be used to produce premium sawlog

Table 5. Least square means cubic-foot product volumes (i.b.) for 454 felled trees by age 6 and 11 treatments for 29-year-old loblolly pine.[1]

Volume type	Age 6 Treatment			Age 11 Treatment		
	TRT1_	TRT2_	TRT3_	TRT_1	TRT_2	TRT_3
	ft^3					
Total	21.75 ±0.70	20.51 ±0.61	20.88 ±0.73	29.91^{a} ±0.92	18.33^{b} ±0.53	14.90^{c} ±0.52
Sawlog	14.79 ±0.82	13.78 ±0.72	13.90 ±0.86	25.15^{a} ±1.07	10.68^{b} ±0.62	6.65^{c} ±0.61
Butt log	7.39 ±0.44	7.16 ±0.38	7.53 ±0.46	12.88^{a} ±0.58	5.93^{b} ±0.33	3.27^{c} ±0.33
Butt bolt	4.44 ±0.23	4.20 ±0.20	4.35 ±0.24	7.16^{a} ±0.31	3.57^{b} ±0.18	2.25^{c} ±0.17

[1] Means with the same letter for each response variable do not differ significantly at the α = 0.10 level.

Table 6. Least square means cubic-foot product volumes (i.b.) for 454 felled trees by treatment combinations for 29-year-old loblolly pine.[1]

Volume type	Treatment								
	TRT11	TRT12	TRT13	TRT21	TRT22	TRT23	TRT31	TRT32	TRT33
	ft^3								
Total	32.70^{a} ±1.56	17.45^{c} ±0.98	15.09^{d} ±1.04	27.46^{b} ±1.42	18.96^{c} ±0.88	15.11^{d} ±0.80	29.56^{a} ±1.81	18.59^{c} ±0.93	14.50^{d} ±0.88
Sawlog	28.16^{a} ±1.82	9.65^{c} ±1.14	6.56^{d} ±1.22	22.26^{b} ±1.67	11.82^{c} ±1.03	7.27^{d} ±0.93	25.03^{a} ±2.11	10.57^{c} ±1.08	6.11^{d} ±1.02
Butt log	13.79^{a} ±0.98	5.27^{c} ±0.61	3.12^{d} ±0.65	11.43^{b} ±0.89	6.69^{c} ±0.55	3.36^{d} ±0.50	13.43^{a} ±1.13	5.82^{c} ±0.57	3.34^{d} ±0.55
Butt bolt	7.64^{a} ±0.52	3.26^{c} ±0.33	2.43^{d} ±0.35	6.39^{b} ±0.48	3.98^{c} ±0.29	2.23^{d} ±0.27	7.47^{a} ±0.60	3.47^{c} ±0.31	2.11^{d} ±0.29

[1] Means with the same letter for each response variable do not differ significantly at the α = 0.10 level.

Table 7. Average individual tree cubic-foot volume (i.b.) product breakdown by treatment combination for 29-year-old loblolly pine.

Volume type	Treatment								
	TRT11	TRT12	TRT13	TRT21	TRT22	TRT23	TRT31	TRT32	TRT33
	ft^3								
Butt bolt	8.1 ±1.8	3.6 ±2.7	2.1 ±2.4	6.5 ±2.3	3.8 ±2.3	2.4 ±2.7	7.3 ±2.7	3.4 ±2.6	2.3 ±2.5
Butt log	14.6 ±3.3	5.9 ±5.1	2.5 ±4.0	11.7 ±4.1	6.3 ±4.7	3.7 ±5.1	13.0 ±4.8	5.8 ±4.9	3.4 ±4.7
Sawlog	29.9 ±8.8	10.9 ±9.5	5.2 ±6.4	22.7 ±9.0	10.9 ±8.2	8.0 ±10.1	24.3 ±11.2	10.4 ±8.9	6.9 ±8.1
Chip-n-Saw	2.4 ±1.3	4.3 ±1.9	4.6 ±2.3	2.6 ±1.4	4.4 ±1.8	4.1 ±2.8	2.3 ±1.8	4.7 ±2.0	4.4 ±2.5
Chips	1.9 ±0.7	3.2 ±1.5	3.9 ±1.3	2.4 ±0.6	2.8 ±1.3	3.5 ±1.6	2.0 ±0.7	3.1 ±1.1	3.7 ±1.5
Top	0.1 ±0.1	0.2 ±0.1	0.1 ±0.1	0.2 ±0.1	0.2 ±0.1	0.2 ±0.1	0.1 ±0.1	0.1 ±0.1	0.2 ±0.1
Total	34.3 ±8.0	18.6 ±8.0	13.9 ±5.6	27.9 ±7.9	18.2 ±6.4	15.7 ±9.0	28.8 ±9.8	18.5 ±7.1	15.2 ±7.2

trees containing up to 28 percent clear wood in the butt logs on a 30-year rotation. As the demand for clear wood increases, pruned sawtimber trees will increase in importance and value.

CONCLUSIONS

1. Two-step pruning is required for maximum clear wood formation in butt sawlogs.
2. First-phase pruning of 100 to 125 crop TPA should include a precommercial thinning to 400 TPA.
3. Second-phase pruning should be done in conjunction with a severe commercial thinning to 100 TPA.

LITERATURE CITED

Banks, P. F. and M. J. Prevost. 1976. Sawlog pruning regimes for *Pinus patula, P. elliottii* and *P. taeda* in Rhodesia. S. African For. Jour. 99:44-48.

Bennett, F. A. 1955. The effect of pruning on height and diameter growth of planted slash pine. J. For. 53 :636-638.

Foil, R. R., T. Hansbrough, and R. G. Merrifield. 1964. Development of loblolly pine as affected by early cultural treatments. Hill Farm Facts-Forestry 5. N.La. Hill Farm Expt. Sta., LSU, 5p.

Labyak, L. F. and F. X. Schumacher. 1954. The contribution of its branches to the main-stem growth of loblolly pine. J. For. 52 :333-337

Locatelli, J. 1977. Why and how should silver fi in the Vosges be pruned? Revue Forestiere Francaise 29 : 375-380.

Shepard, R. D. 1974. Effect of initial spacing and thinning on the growth and development of loblolly pine. Hill Farm Facts - Forestry 10 N. La. Hill Farm Expt. Sta., LSU. 35p.

Sprinz, P., T. Clason, and D. Bower. 1979. Spaci and thinning effects on the growth and development of a loblolly pine plantation, p. 1-42. In Clason, T. R. (Ed.), Forestry Research Report. 1979. N.La.Hill Farm Expt. Sta., LSU.

Vel, E. M. 1975. Some supplementary data on the pruning of *Pinus caribaea* var. *hondurensis*. CELOS Rapporten No. 94, 20p.

Wakeley, P. C. 1954. Planting the southern pine. USDA Forest Service Agricultural Monograph 18. 233p.

Young, H. E. and P. J. Kramer. 1952. The effect of pruning on the height and diameter growth of loblolly pine. J. For. 50 :474-479.

SOME SHORT-TERM EFFECTS OF THINNING AND PRUNING IN YOUNG LOBLOLLY PINE PLANTATIONS[1]

James D. Burton[2]

Abstract.--Three years after an old-field loblolly pine plantation was thinned and pruned to 4 basal areas and 3 live crown ratios, stemwood volume growth was greatest under the lightest thinning and unaffected by pruning. Stem form improved most under the severest thinning and pruning.

INTRODUCTION

Loblolly pine sawtimber can be grown in antations in rotations of 21 to 27 years, with avy thinning, low pruning, and understory ntrol (Burton and Shoulders 1974). But how uld lighter levels of thinning and higher levels pruning affect stemwood volume growth early in e rotation? This paper reports some 3rd-year sults of a study established to answer this estion.

PROCEDURES

Description of Study Area

The study was installed in an old-field blolly pine plantation near Monticello, Ark.[3] e stand had been machine-planted at a spacing about 6 by 6 ft. in winter 1958-59. When the udy began, the plantation was 11 years old. It ntained 565 pine stems/acre with a basal area 107 ft^2/acre. The d.b.h. range was 1 to 11 ches; 475 stems/acre were ≥ 4.6 inches d.b.h.; e 5-inch class had 18 percent of the total pine ems/acre, the 6-inch class had 32 percent, and e 7-inch class had 25 percent. Dominant and dominant trees averaged 37 feet tall, and their ve crown length was 59 percent of total height.

The unthinned plantation had very few hardwood trees; none had a dominant or codominant crown, and all were felled when the study began. There was no woody understory at age 11.

The soils are Tippah and Sacul silt loams. The A1 horizon is 3 to 4 inches thick. Slopes are 0 to 4 percent to the south.

Thirty-six square 0.4-acre plots were laid out and were organized into three blocks according to severity of erosion that had occurred when the land was in row crops. In block I, where evidence of erosion was strongest, basal area averaged 99 ft^2/acre and no plot had less than 90 ft^2/acre. In block II no plot had less than 98 ft^2/acre, and in block III no plot had less than 105 ft^2/acre.

Treatments

At age 11, four thinning levels (very light, light, heavy, and very heavy) and three pruning levels (low, medium, and high) were applied in all 12 possible combinations. Thinning left basal areas of 100, 80, 60, or 40 ft^2/acre in merchantable trees (≥ 4.6 inches d.b.h. containing ≥ two 63-inch bolts to a 3-inch top d.i.b.). Trees smaller than this were submerchantable and were removed in the first thinning. Where possible, thinning was from below. But need to achieve uniform spacing and to remove forked and crooked trees, wolf trees, and trees with fusiform rust stem galls required cutting many dominant and codominant trees; so did the reduction of basal area to 40 ft^2/acre.

The low level of pruning left a live crown 19 feet long, equal to 52 percent of tree height. High pruning left a crown length of 13 feet (37 percent), and medium pruning left a 15-ft. crown (41 percent).

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[1] Paper presented at Southern Silviltural Research Conference, Atlanta, Georgia, vember 6-7, 1980.

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[3] Land and technical assistance were ovided by the Crossett Division, Georgia-Pacific rporation.

The low level of pruning was mild; in lightly and very lightly thinned plots, most trees had some lower limbs dead of suppression at age 14. Even under very heavy thinning, low pruning did not greatly reduce the photosynthetic capacity. High pruning did: some trees had only 2 annual whorls, with intervening short branches, and the leader.

Measurements and Analysis

All measurements were made in the 0.1-acre square plot at the center of each 0.4-acre treatment plot. The plots were inventoried before treatment at age 11 and before treatment at age 14. The first and every fifth tree measured in each 1-inch d.b.h. class ($\geq$ 4.6 inches) were chosen as sample trees for additional measurements until each plot had 12 sample trees. I measured upper bole diameters and heights with a magnifying optical dendrometer and got bole volumes, total and to a 4-inch top, by the height accumulation method (Lohrey and Dell 1969). To obtain stemwood diameter inside bark from stem diameter outside bark, I derived a conversion factor from paired d.o.b. and d.i.b. measurements at 4 points along the stem of 108 trees felled in thinning.

The height accumulation program computed cubic-foot volume and basal area for each sample tree. The summary program computed volume/acre of each plot by multiplying the mean volume/basal area ratio of the sample trees by the plot basal area/acre. After-cut volume/acre was determined from the mean volume/basal area ratio of sample trees left (usually fewer than 12 trees) and the after-cut basal area/acre.

Absolute form quotient was calculated as:

$$\text{AFQ} = \frac{(\text{bole d.o.b. midway between b.h. and apex})}{\text{d.b.h.}}$$

Using randomized complete blocks with 3 replications, I examined treatment-associated differences in growth parameters through analysis of variance. I used Duncan's Multiple Range Test to evaluate differences between treatment means when the thinning and pruning interaction was significant (at the .05 level) and to evaluate main effects of thinning and pruning when interaction was not significant.

RESULTS

Growth in D.b.h.

Periodic growth in d.b.h. was greatest in the very heavy, least in the very light thinning treatment, and all four thinning means were significantly different (table 1). Annual d.b.h. growth between ages 11 and 14 averaged .59 inch in the very heavy, .45 inch in the heavy, .34 inch in the light, and .27 inch in the very light. Growth in d.b.h. was significantly less under high than under low pruning. The thinning and pruning interaction was not significant.

Table 1.--Periodic growth in mean d.b.h., age 11-14, of trees surviving to age 14

Pruning level	Thinning level Very heavy	Heavy	Light	Very light	Pruning means
	------------inches------------				
High	1.61	1.30	.92	.80	1.16 a[1]
Medium	1.79	1.37	1.00	.78	1.24 ab
Low	1.87	1.38	1.12	.80	1.29 b
Thinning means	1.76 a	1.35 b	1.02 c	.80 d	1.23

1/ Means followed by the same letter, withi a row or a column, are not significantly different at the .05 level.

For all surviving trees, periodic growth in d.b.h. per foot of height growth was significantly less under high pruning than under low pruning and was nearly twice as great under very heavy thinning as under light and very light thinning (table 2). With greatly increased growing space, trees became more stocky; with high pruning, trees became more slender. Treatments affected stem form.

Table 2.--Periodic d.b.h. growth per foot of periodic height growth

Pruning level	Thinning level Very heavy	Heavy	Light	Very light	Pruning means
	------------inches------------				
High	.25	.19	.14	.12	.18 a[1]
Medium	.26	.19	.17	.14	.19 ab
Low	.32	.19	.16	.15	.21 b
Thinning means	.28 a	.19 b	.16 c	.14 c	.19

1/ Means followed by the same letter, withi a row or a column, are not significantly different at the .05 level.

able 3.--Periodic annual growth in total stemwood, inside bark, including leader

runing evel	Thinning level Very heavy	Heavy	Light	Very light	Pruning means
	ft³/acre				
igh	228	286	280	320	279 a[1]
edium	220	284	310	308	280 a
ow	232	287	334	356	302 a
hinning eans	227 a	286 b	308 bc	328 c	287

[1] Means followed by the same letter, within row or a column, are not significantly different the .05 level.

Growth in Cubic-Foot Volume and Height to a 6-inch Top

Growth in total stemwood, inside bark to a ero top, was significantly lower with heavy thinning, and even lower with very heavy thinning, than th very light thinning (table 3). With all runing levels combined, periodic annual growth nged from 328 ft³/acre under very light thinning 227 ft³/acre under very heavy. There were no portant differences among pruning means.

Periodic annual growth in height to a 6-inch p was greatest under very heavy thinning, sig- ficantly less under heavy, and even less under ght and very light thinning (table 4). There re no important differences among pruning means.

Basal Area Growth

Periodic annual growth in basal area was eatest under low pruning and significantly re- ced by medium and high pruning (table 5); but it s vigorous in every treatment. Differences among inning means were not important.

Stem Form

Absolute form quotient increased under all eatments: stem form became more cylindrical. erall mean AFQ was .62 at age 11 and .65 at age . The interaction of thinning and pruning was gnificant: differences due to pruning occurred ly under heavy and very heavy thinning (table 6). der very heavy thinning, the high-pruning mean s greater than the low-pruning mean but not the dium pruning mean. Under light and very light inning, pruning did not significantly affect em form.

Table 4.--Periodic annual growth in height to a 6-inch top d.o.b. in sample trees

Pruning level	Thinning level Very heavy	Heavy	Light	Very light	Pruning means
	feet				
High	4.8	4.1	2.6	2.6	3.5 a[1]
Medium	4.3	3.3	2.5	2.4	3.1 a
Low	4.0	3.3	3.1	2.3	3.2 a
Thinning means	4.3 a	3.6 b	2.7 c	2.4 c	3.3

[1] Means followed by the same letter, within a row or a column, are not significantly different at the .05 level.

Table 5.--Periodic annual growth in basal area

Pruning level	Thinning level Very heavy	Heavy	Light	Very light	Pruning means
	ft²/acre				
High	7.11	7.89	8.00	8.22	7.81 a[1]
Medium	7.67	9.11	7.44	7.67	7.97 a
Low	8.67	9.11	9.33	9.00	9.03 b
Thinning means	7.81 a	8.70 b	8.26 ab	8.30 ab	8.27

Means followed by the same letter, within a row or a column, are not significantly different at the .05 level.

Table 6.--Periodic annual increase in absolute form quotient

Pruning level	Thinning level Very heavy	Heavy	Light	Very light	Pruning means
High	.049 a[1]	.039 ab	.021 c	.033 bc	.036
Medium	.029 bc	.036 b	.028 bc	.032 bc	.031
Low	.027 bc	.021 c	.021 c	.030 bc	.025
Thinning means	.035	.032	.023	.032	.030

[1] Means followed by the same letter, within a row or a column, are not significantly different at the .05 level.

DISCUSSION

Periodic basal area growth in young loblolly pine stands usually varies directly, but not greatly, with residual basal area, being only slightly affected by thinnings removing as much as 50 percent of pretreatment basal area (Wahlenberg 1960).

Under light and very light thinning, natural crown-shortening proceeded so far that artificial pruning actually did little to further shorten live-crown length. Heavy and very heavy thinning so thoroughly released the residual trees that natural pruning stopped temporarily. The lowest limbs remained alive and vigorous, and pruning them caused a real difference in stem form.

A thinning that removes dominant and codominant trees encourages development of increased taper in residual trees (table 2). Thinning from below ordinarily has no measurable effect on stem form (Larson 1963). Very light and light thinnings in this study were mainly from below, but heavy and very heavy thinning harvested many dominant-stand trees. The effect of pruning on stem form is directly opposite that of thinning from above. Research elsewhere (Luckhoff 1949, Labyak and Schumacher 1954, and Marts 1949, among others) with loblolly pine and other conifers, has shown that removal of $\geq$ 20 percent of the green crown reduces diameter growth and causes trees to develop a more cylindrical bole. After a few years, stem taper and growth rate return to normal, if prunings are not repeated. This return to normal does not mean that d.b.h. of pruned trees will soon equal that of the unpruned. Stem form in young even-aged pine stands during the linear period of height growth improves rapidly with increasing age (Larson 1963). Williston (1967) reported that form class of crop trees in loblolly pine plantations in Tennessee, from age 19 to age 29, increased more in plots thinned from below than in unthinned plots. In thinning studies elsewhere (Boggess and McMillan 1955, Brinkman et al. 1965) in pine plantations and natural stands, the largest, fastest-growing trees developed the least taper and made the greatest short-term improvement in stem form. These differences usually are temporary; all surviving trees, without more cultural treatment, usually approach a common stem form characteristic of the species and tree size.

LITERATURE CITED

Boggess, W. R. and R. W. McMillan.
1955. Changing volume and taper of pole-size shortleaf pine in southern Illinois. Ill. Agric. Exp. Stn. For. Note No. 66, 4 p. Univ. Ill., Urbana.

Burton, J. D., and E. Shoulders.
1974. Fast-grown, dense loblolly pine sawlogs: a reality. J. For. 72:637-641.

Brinkman, K. A., N. F. Rogers, and S. F. Gingrich.
1965. Shortleaf pine in Missouri, stand density affects yield. U. S. Dep. Agric. For. Serv. Res. Pap. CS-14, 14 p. Central States For. Exp. Stn., Columbus, Ohio.

Labyak, L. F., and F. X. Schumacher.
1954. The contribution of its branches to the main-stem growth of loblolly pine. J. For. 52:333-337.

Larson, P. R.
1963. Stem form and silviculture. Soc. Am. For. Proc. 1963: 103-107. Washington, D.C.

Lohrey, R. E., and T. R. Dell.
1969. Computer programs using height accumulation for tree volumes and plot summaries. J. For. 67:554-555.

Luckhoff, H. A.
1949. The effect of live pruning on the growth of *Pinus patula, P. caribaea,* and *P. taeda.* J. S. Afr. For. Assoc. 18:25-55.

Marts, R. O.
1949. Effect of crown reduction on taper and density in longleaf pine. South. Lumberman 197 (2249):206-209.

Wahlenberg, W. G.
1960. Loblolly pine. Duke Univ. Sch. of For. and For. Serv., U. S. Dep. Agric. xxii + 603 p.

Williston, H. L.
1967. Thinning desirable in loblolly pine plantations in west Tennessee. U. S. Dep. Agric. For. Serv. Res. Note SO-61. 7 p. South. For. Exp. Stn., New Orleans, La.

DIAMETER DISTRIBUTIONS MODELS

FOR

REPEATEDLY THINNED SLASH PINE PLANTATIONS[1]

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Abstract.--This paper reports the results of an effort to determine if traditional diameter distribution modeling methods can be applied to repeatedly thinned pine plantations. Data are from 297 plots in slash pine plantations thinned and remeasured up to five times over a period of about 20 years. The Weibull distribution fitted diameter distributions quite well -- as well as it and other distributions have fitted data from unthinned stands. Models to predict and project the 24th, 63rd, and 93rd percentiles of distributions were developed for unthinned stands, stands after first thinning, and following a growth period of variable length. An analysis of before and after thinning distributions showed no difference except at the first thinning. The first thinning, primarily a thinning from below, tended to shift the distribution toward large trees (more negative skewness). An example is provided with the models applied to project the distributions before and after thinning at ages 15, 20, and 25 and final distribution at age 30.

INTRODUCTION

Foresters have long been interested in thin- ng as a method of stimulating growth and pro- ing higher quality sawlogs. However, planta- on forestry in the South and the Southeast has been characterized in the sixties and seventies by a "plant 'em thick and cut 'em quick" type of silviculture with almost total emphasis on pulp fiber production. There are no clear advantages to thinning in such a system. With increasing emphasis in recent years on solid wood products, primarily lumber and veneer, and a diminishing supply of high quality sawlogs from natural stands, interest has returned to the practice of thinning. Along with this returned emphasis comes a need to predict stand structure (volumes, tree heights, log lengths, etc., by diameter classes).

In this paper we report on an analysis which looked at one very important aspect of predicting stand structure of thinned plantations, the diameter distribution. Data from repeatedly thinned and remeasured slash pine plantations were analyzed to determine whether or not smooth distribution functions can be used as models, and if before and after thinning distributions are different in shape. Regression equations are presented which can be used to predict three diameter distribution percentiles for unthinned and thinned plantations of slash pine. A method of obtaining parameters of the Weibull distribution from the percentiles is also explained.

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[1] Paper presented at the Southern Silvi- ltural Research Conference, Atlanta, Georgia, vember 6-7, 1980.

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THE DATA BASE

Data for these analyses come from the Southeastern Forest Experiment Station study known as the Slash Pine Plantation Stand Density Study. Several publications have resulted, either totally or in part, from this study (Bennett, 1970; Bennett and Clutter, 1968; Field et al. 1978; and Clutter and Jones, 1980). Clutter and Jones (1980) give a brief overview of the study, part of which is repeated here for completeness. However, some details of the description of the data differ from their report since the analysis reported here is the first to use all remeasurements of the plots.

The study, begun in 1958, represents a cooperative effort of the USDA Forest Service, Southeastern Forest Experiment Station, and 18 landowners[1]. The 297 plots (each approximately 1/4-acre in size) were distributed across 4 states,

State	Number of Plots
Georgia	180
Florida	104
Alabama	8
Mississippi	5
	297

and across 3 physiographic provinces,

Province	Number of Plots
Upper Coastal Plain	65
Middle Coastal Plain	145
Lower Coastal Plain	87
	297

Plantations sampled had been established on old-fields and had no evidence of frequent or damaging fires, naval stores operations, heavy rust infection, or interplanting. No more than six merchantable-size wild pines or hardwoods were allowed on a selected plot.

Each plot was randomly assigned a residual basal area class for thinning treatment,

Basal Area Class -square feet-	Number of Plots
15	3
40	69
65	71
90	69
115	49
140	27
165	9

At each measurement, including installation, each plot was thinned to the midpoint (± 12.5 square feet) of its assigned class if not already within the class range. This was done with an improvement cut from below, removing mostly smaller trees with some large trees taken if disease, poor stem quality, or spacing justified their removal. The leaving of large, unoccupied spaces in stands was avoided. Plots were well distributed over ages 9 to 32 years, site index (base age 25) 38 to 80 feet, and 100 to 1180 trees per acre at age of installation (Tables 1-3).

Table 1.--Slash Pine Stand Density Study--Distribution of plots by age at installation and site index (base age 25).

Age Class	Site Index Class (feet)					
	30-39	40-49	50-59	60-69	70-79	80-89
	---------number of plots---------					
10	1	4	9	48	37	0
15	0	5	18	49	8	0
20	2	0	13	42	27	1
25	0	1	6	16	4	0
30	0	0	2	4	0	0
Total	3	10	48	159	76	1

At plot installation (measurement number 1) and a each subsequent remeasurement, all diameters were recorded to the nearest tenth of an inch. Total height, height to live crown, and crown class wer recorded on the first and every eighth tree thereafter in each diameter class encountered. Thinnings were carried out at 646 of the 1188 total plot visits (Table 4). Nine plots were never remeasured after installation while 13 plots were remeasured 5 times. The interval between measurements ranged from one to ten years with the majority of plots being remeasured on a 5-year cycl

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[1] In alphabetical order: Brunswick Pulp Land Company; Buckeye Cellulose Corporation; Container Corporation of America; Continental Forest Industries; Florida Department of Agriculture and Consumer Services, Division of Forestry; Georgia Kraft Company; International Paper Company; ITT Rayonier, Incorporated; O. F. McEachin Estate, McRae, Georgia; Jesse Newsom Estate, Davisboro, Georgia; Owens-Illinois, Forest Products Division; Mr. W. C. Peterson, Soperton, Georgia; Mr. Joe Prescott, Lumber City, Georgia; St. Regis Paper Company; Sullivan Lumber Company; Union Camp Corporation; U.S. Forest Service, Florida National Forests; and H. E. Walton Estate, Cordele, Georgia.

Table 2.--Slash Pine Stand Density Study--Distribution of plots by age and stems per acre at installation.

Age Class	Stems Per Acre											Total
	100-199	200-299	300-399	400-499	500-599	600-699	700-799	800-899	900-999	1000-1099	1100-1199	
	number of plots											
10	0	1	2	18	27	20	16	6	4	2	3	99
15	4	13	15	14	10	13	7	2	2	0	0	80
20	16	19	22	16	4	5	0	0	2	0	1	85
25	12	9	1	3	2	0	0	0	0	0	0	27
30	4	2	0	0	0	0	0	0	0	0	0	6
Total	36	44	40	51	43	38	23	8	8	2	4	297

Table 3.--Slash Pine Stand Density Study--Distribution of plots by site index (base age 25) and stems per acre at installation.

Site Index	Stems Per Acre											Total
	100-199	200-299	300-399	400-499	500-599	600-699	700-799	800-899	900-999	1000-1099	1100-1199	
	number of plots											
30-39	1	0	1	0	0	0	1	0	0	0	0	3
40-49	0	2	3	1	0	0	2	1	0	1	0	10
50-59	5	6	6	11	7	7	0	2	4	0	0	48
60-69	23	26	17	29	19	18	13	5	4	1	4	159
70-79	7	9	13	10	17	13	7	0	0	0	0	76
80-89	0	1	0	0	0	0	0	0	0	0	0	1
Total	36	44	40	51	43	38	23	8	8	2	4	297

Growth Period Length --years--	Number of Cases
1	12
2	14
3	25
4	62
5	716
6	50
7	8
8	3
9	0
10	1

ANALYSIS AND MODEL DEVELOPMENT

Testing Smooth Distribution Curves

Since the turn of the century smooth distribution curves of several types, primarily statistical distribution functions, have been used in forestry to characterize distributions of diameters. Most recent diameter distribution modeling work for unthinned conifer plantations has relied on the Weibull distribution introduced for this purpose by Bailey and Dell (1973). This function has also found use in modeling natural stands of conifers (Schreuder et al., 1979), natural mixed-species of Appalachian hardwoods (Stiff, 1979), and uneven-aged mixed northern hardwoods (Hyink, 1979). To our knowledge, the use of this function or any other smooth distribution function with data from thinned conifer stands has not been thoroughly explored.

The equation of the Weibull probability density function is

$$f(x) = (c/b)[(x-a)/b]^{c-1} e^{-[(x-a)/b]^{c}}, \quad a \leq x < \infty \qquad (1)$$

$$= 0 \quad , \quad \text{elsewhere,}$$

where x is d.b.h. and the coefficients, a, b, and c, must be estimated from data or predicted with models. Bailey and Dell (1973) discuss characteristics of the Weibull which make it useful as a diameter distribution model.

With the algorithm for maximum likelihood estimation proposed by Wingo (1972), equation (1) was fitted to data from each measurement of each plot both before and after thinning. Several checks for goodness of fit were then applied. The Kolmogorov-Smirnov test (Massey, 1951) at the 0.05 level rejected the Weibull for 5.02% of the before-thinning cases and 4.67% of the after-thinning cases. Before and after thinning refers to the stand immediately before and after trees are removed, without regard to the overall thinning history of the stand. As another check, quadratic mean diameter (D_q), minimum diameter (D_m), and maximum diameter (D_x) were compared for the observed and fitted distributions. Defining deviations by the function

$$\Delta(y) = (\text{observed } y) - (\text{predicted } y),$$

summaries were developed for $\Delta(D_q)$, $\Delta(D_m)$, and $\Delta(D_x)$. The after-thinning data fitted the Weibull model as well as the before-thinning data (Table 5). In both instances, the fit was judged to be acceptable.

Table 4.--Slash Pine Stand Density Study--Numbers of plots by age at measurement and measurement number.

Age	Measurement Number 1	2	3	4	5	6	Totals
	----------number of plots---------						
9	6						6
10	17						17
11	26						26
12	29						29
13	27	3					30
14	24	3					27
15	8	15	1				24
16	11	29	0				40
17	24	33	0				57
18	12	25	4				41
19	14	12	4				30
20	16	4	9	1			30
21	24	9	23	0			56
22	16	20	37	3			76
23	11	20	18	4			53
24	13	11	18	2			44
25	2	16	6	11	1		36
26	7	17	8	40	0		72
27	4	32	26	12	0		74
28	0	5	9	26	3		43
29	1	16	10	5	2		34
30	2	1	8	6	0		17
31	0	4	26	13	8		51
32	3	7	21	15	4		50
33		0	14	7	12		33
34		1	9	2	2	2	16
35		2	1	17	0	0	20
36		0	3	25	8	0	36
37		3	7	18	5	0	33
38			1	11	7	3	22
39			0	4	2	5	11
40			2	0	3	1	6
41			0	7	3	0	10
42			0	3	12	2	17
43			3	0	4		7
44				0	5		5
45				2	0		2
46				0	0		0
47				3	2		5
48					0		0
49					0		0
50					0		0
51					2		2
Totals	297	288	268	237	85	13	1188

able 5.--Summaries of deviations for quadratic mean (D_q), minimum (D_m), and maximum diameter (D_x).

eviations/	Before Thinning	After Thinning
---inches---	--------percent of cases--------	
(D_q):		
-0.1 to +0.1	80	79
-0.3 to +0.3	96	96
-0.5 to +0.5	98	98
$(D_q) \leq 0$	40	44
$(D_q) \geq 0$	60	56
(D_m):		
-1.0 to +1.0	74	76
-3.0 to +3.0	94	97
$(D_m) \leq 0$	60	57
$(D_m) \geq 0$	40	43
(D_x):		
1.0 to +1.0	92	95
3.0 to +3.0	98	99
$(D_x) \leq 0$	75	71
$(D_x) \geq 0$	25	29

/$\Delta(y)$ = (observed y) - (predicted y)

The next step was to examine whether or not
inning by the method applied in this study sig-
ficantly changed the shape of the diameter dis-
ibution. In a row thinning, trees are not re-
ved according to a size criterion, so an assump-
on that the before and after-thinning relative
stributions are the same would be tenable. How-
er, with the thinning methods applied in this
udy, size (diameter) and probability of removal
ould be inversely related. This could lead to a
ange in the relative distribution.

Again the Kolmogorov-Smirnov test was em-
oyed. When the observed distributions were con-
rted to percentages and tests made at the 0.05
vel for different underlying distributions be-
re and after thinning, 11.4% (74 plot measure-
nts) of the tests were significant. Of those,
cases were from initial thinnings. For stands
ich had been subjected to thinning in the past,
ly 1.6% of the cases had different before and
ter thinning distributions. This implies that
ce a thinning regime was started, thinnings sub-
quent to the first one did not alter the rela-
ve distribution of diameters. With these re-
lts in mind, we proceeded to design a system of
gression equations to predict before and after
inning distributions and to predict change in
e distribution due to growth based on the Weibull
a model.

Predicting the Weibull Parameters

Past applications of the diameter distribution approach to yield model development usually involved regressions to predict the parameters of a chosen distribution. Such regressions have been developed using either maximum likelihood or moment estimates for the parameters as dependent variables and stand characteristics (age, site index, trees per acre, etc.) as independent variables. In most published work, one or more of the parameters was poorly regressed ($r^2 \leq 0.10$). This has been true with both the beta distribution and the Weibull. It was true for our data as well. We could not obtain acceptable regressions to predict the maximum likelihood estimates of Weibull parameters.

A likely reason for the poorly defined regressions experienced is that quite similar appearing distributions, in terms of shape and peakedness, may result from different sets of parameter estimates. This is simply variation introduced through the fitting process. However, we reasoned that statistics computed directly from the data may be more predictable since no process of curve fitting would be involved. If reliable regressions could be obtained to predict those statistics, they could then be equated to theoretical values as defined with equation (1). The resulting system of equations could thus be solved for predicted values of the distribution parameters.

A number of different sample statistics could be used in this approach: mean, mode, variance, minimum and so on. For a 3-parameter model like equation (1), three such statistics would be necessary. Since the k'th moment of the Weibull probability density function contains the expression

$$\Gamma(1 + k/c) = \int_0^\infty t^{k/c} e^{-t} dt$$

and solving for c would lead to complications, we choose not to use moments. Instead, we elected to predict percentiles since the p'th distribution percentile of the Weibull is a tractable equation:

$$D_p = a + b[-\ln(\frac{100-p}{100})]^{(1/c)}, \qquad (2)$$

where D_p is that diameter such that exactly p percent of the trees in the stand are smaller.

For p we chose 24, 63, and 93. Although somewhat arbitrary and much work could be done toward defining optimum choices, our decision was based on the fact that Dubey (1967) showed p = 24 and p = 93 to be jointly best for estimation of b and c when a = 0 is specified (i.e. two-parameter Weibull). Further, p = 63 was chosen because this value gives $D_p = a + b$, a much simplified expression.

These three percentiles were computed directly from the measured diameters for each stand, both before and after thinning, at each measurement age. Linear interpolation was used where necessary to obtain the percentile. For example, if the 20th percentile was at 5.2 inches and the 25th percentile was at 5.3 inches,

$$D_{24} = 5.2 + 0.1(4/5)$$
$$= 5.28$$

With regression screening methods (SAS Institute, 1979), the following equations to predict these three percentiles for unthinned stands were obtained with data from measurements of stands not thinned up to the time of measurements:

$$D_{24u} = -8.0067 + 0.0662A -2.0764\ \ln(T_s) + 6.0138\ \ln(S) \quad (3)$$

$$R^2 = 0.72 \qquad s_{y.x} = 0.90$$

$$D_{63u} = 3.5796 + 2.8233\ \ln(A) - 376.7283/S + 627.1906/T_s \quad (4)$$

$$R^2 = 0.93 \qquad s_{y.x} = 0.26$$

$$D_{93u} = -8.0355 + 4.1228\ \ln(H) + 616.9904/T_s -65.6214/S\ , \quad (5)$$

$$R^2 = 0.92 \qquad s_{y.x} = 0.35,$$

where $\ln(H)$ = natural logarithm of dominant height (H) in feet,
A = age in years,
T_s = surviving trees per acre,
S = base-age-25 site index in feet,
and D_{pu} = the p'th percentile of the diameter distribution of an unthinned plantation.

Equations (3), (4), and (5) were used to predict distribution percentiles and equation (2) was used to define a system of 3 equations in the 3 parameters. Solution of the equations for a, b, and c allowed predicted distributions to be generated. Exact procedures for obtaining the solutions are covered in the next section of this paper. Based on the Kolmogorov-Smirnov test, only 3.1 percent of the predicted distributions were found different from the observed distributions at the 0.05 level. In addition, 78% of the cases had predicted quadratic mean diameters within ±0.5 inch of the observed (Table 6).

In some cases, the solution to a system of equations defined as above gave negative estimates for a. When this occurred, $\hat{D}_{24}$ and $\hat{D}_{93}$ were used to solve for b and c with a assumed to be zero.

Based on data for stands at first thinning, the following regressions were developed:

Table 6.--Summaries of deviations for quadratic mean (D_q), minimum (D_m), and maximum (D_x) diameter for unthinned stands.

Deviations[1/]	Percent of Cases
----inches----	
$\Delta(D_q)$:	
-0.5 to +0.5	78
-1.0 to +1.0	99
Average = +0.13	
$\Delta(D_m)$:	
-1.0 to +1.0	70
-2.0 to +2.0	90
Average = 0.60	
$\Delta(D_x)$:	
-1.0 to +1.0	82
-2.0 to +2.0	93
Average = +0.20	

[1/] $\Delta(y)$ = (observed y) - (predicted y)

$$D_{24a} = -0.6617 + 0.2026\ D_{24b} + 0.8064\ D_{qb} + 1.3855\ B_r \quad (6)$$

$$R^2 = 0.90 \qquad s_{y.x} = 0.60$$

$$D_{63a} = 0.9605\ D_{63b} + 0.0212\ A + 0.8032\ B_r \quad (7)$$

$$R^2 = 0.99 \qquad s_{y.x} = 0.26$$

$$D_{93a} = -0.1044 + 1.0967\ D_{93b} - 0.0953\ D_{qb} + 0.2890\ B_r \quad (8)$$

$$R^2 = 0.99 \qquad s_{y.x} = 0.21,$$

where D_{pa} = p'th percentile after thinning,
D_{pb} = p'th percentile before thinning,
D_{qb} = D_q before thinning, all in inches,
A = age in years,
and B_r = basal area removed as a proportion basal area before thinning.

None of the distributions generated by this system were declared significantly different from the observed and 91% of the cases had $\Delta(D_q)$ withi ±0.5 inches (Table 7).

Based on 825 cases where a stand was thinned one or more times and remeasured after some growt interval, the following regressions were fitted:

Table 7.--Summaries of deviations for quadratic mean (D_q), minimum (D_m), and maximum (D_x) diameter for predicting distributions left immediately after first thinning.

Deviations[1]	Percent of Cases
----inches----	
$\Delta(D_q)$:	
-0.5 to +0.5	91
-1.0 to +1.0	98
Average = 0.09	
$\Delta(D_m)$:	
-1.0 to +1.0	69
-2.0 to +2.0	86
Average = 0.12	
$\Delta(D_x)$:	
-1.0 to +1.0	86
-2.0 to +2.0	96
Average = -0.07	

[1] $\Delta(y)$ = (observed y) - (predicted y)

$$D_{24e} = 0.4089 + 1.0314\ D_{24s} - 0.0289\ A -0.0048\ B_s + 0.0101\ S + 0.1211\ t \tag{9}$$

$$R^2 = 0.96 \qquad s_{y.x} = 0.41$$

$$D_{63e} = 0.5334 + 1.0365\ D_{63s} - 0.0358\ A -0.0049\ B_s + 0.0075\ S + 0.1845\ t \tag{10}$$

$$R^2 = 0.98 \qquad s_{y.x} = 0.28$$

$$D_{93e} = 0.5135 + 1.0181\ D_{93s} - 0.0375\ A -0.0045\ B_s + 0.0098\ S + 0.2279\ t \tag{11}$$

$$R^2 = 0.98 \qquad S_{y.x} = 0.34$$

here D_{pe} = p'th percentile at the end of the growth period,
D_{ps} = p'th percentile at the start of the growth period (after thinning if thinned), all in inches,
A = age in years,
B_s = basal area in square feet per acre at the start of the growth period,
S = base-age-25 site index in feet,
and t = length of the growth period in years.

Just as was the situation with the equations or distributions after first thinning, none of he predicted distributions based on equations 9)-(11) were declared significantly different with the Kolmogorov-Smirnov goodness of fit test. In 89% of the cases, predicted quadratic mean diameter was within ±0.5 inch of the observed (Table 8).

Table 8.--Summaries of deviations for quadratic mean (D_q), minimum (D_m), and maximum (D_x) diameter for predicting distributions after growth.

Deviations[1]	Percent of Cases
----inches----	
$\Delta(D_q)$:	
-0.5 to +0.5	89
-1.0 to +1.0	98
Average = 0.10	
$\Delta(D_m)$:	
-1.0 to +1.0	59
-2.0 to +2.0	81
Average = 0.59	
$\Delta(D_x)$:	
-1.0 to +1.0	83
-2.0 to +2.0	94
Average = -0.20	

[1] $\Delta(y)$ = (observed y) - (predicted y)

Converting from Percentiles to Weibull Parameters

As was indicated above, predicted values for D_{24}, D_{63}, and D_{93} together with equation (2) define a system of 3 equations with the parameters a, b, and c as unknowns:

$$D_{24} = a + b[-\ln(0.76)]^{1/c} \tag{12}$$

$$^{1/}\ D_{63} = a + b[-\ln(0.37)]^{1/c} \tag{13}$$

$$= a + b$$

$$D_{93} = a + b[-\ln(.07)]^{1/c} \tag{14}$$

These can be combined to give an expression in c only:

$$\frac{D_{63} - D_{24}}{D_{93} - D_{63}} = \frac{1 - (.2744368)^{1/c}}{(2.6592600)^{1/c} - 1},$$

$$\text{or } \lambda(D_{24}, D_{63}, D_{93}) = \gamma(c) \tag{15}$$

---

[1] The exact value for p in the case of D_{63} is $100(1-e^{-1})$ where "e" is the base of the natural logarithms. To 5 decimals, p = 63.21206.

where the definitions of $\lambda(D_{24}, D_{63}, D_{93})$ and $\gamma(c)$ are implied by the first expression in (15) above. Thus, to calculate predicted values for a, b, and c, $\lambda(D_{24}, D_{63}, D_{93})$ is computed with the predicted percentiles and (15) solved for c. Then b is obtained with the equation

$$b = (D_{63} - D_{24})/[1 - (0.2744368)^{1/c}], \qquad (16)$$

which is derived from (12) and (13) above. Lastly, a can be obtained from either (12), (13), or (14); equation (13) obviously being the easiest to solve.

The function $\gamma(c)$ is quite well behaved (Table 9) and equation (15) can be solved easily and cheaply on a computer with standard methods of numerical analysis. However, to facilitate desk calculator solutions of (15), linear interpolation in table 9 is recommended.

Table 9.--Values for $\gamma(c) = [1 - (.2744368)^{1/c}]/[(2.6592600^{1/c} - 1]$ with c = 0.25 to 12.0 by 0.25.

c	γ(c)	c	γ(c)	c	γ(c)
0.25	0.0203	4.25	1.0137	8.25	1.1526
0.50	0.1523	4.50	1.0287	8.50	1.1572
0.75	0.3061	4.75	1.0423	8.75	1.1616
1.00	0.4373	5.00	1.0547	9.00	1.1658
1.25	0.5431	5.25	1.0661	9.25	1.1697
1.50	0.6283	5.50	1.0765	9.50	1.1735
1.75	0.6976	5.75	1.0861	9.75	1.1771
2.00	0.7549	6.00	1.0950	10.00	1.1805
2.25	0.8028	6.25	1.1033	10.25	1.1838
2.50	0.8434	6.50	1.1109	10.50	1.1869
2.75	0.8783	6.75	1.1181	10.75	1.1898
3.00	0.9084	7.00	1.1248	11.00	1.1927
3.25	0.9348	7.25	1.1310	11.25	1.1954
3.50	0.9581	7.50	1.1369	11.50	1.1980
3.75	0.9787	7.75	1.1424	11.75	1.2005
4.00	0.9972	8.00	1.1476	12.00	1.2029

AN EXAMPLE

As an example of the application of these models, equations (3)-(5) and (6)-(8) were used to determine the parameters of the diameter distribution before and after thinning (fig. 1a) of a 15-year-old plantation with 500 trees per acre and site index of 60 feet at age 25. A light thinning from below was applied by which basal area was reduced by 15% from 92 to 79 square feet per acre, and 394 trees per acre were left (table 10). This amounted to 150 to 180 cu. ft. of merchantable wood (4" o.b. top) per acre removed. The shift in the diameter distribution is obvious (fig. 1a).

To obtain diameter distributions at later ages, a prediction of mortality was necessary. Since an analysis of the full data set for mortality relationships is not complete at this time, the equation given by Clutter and Jones (1980) based on first-remeasurement data was used. In addition, their site index equation was solved for dominant height in order to predict D_{93u} with equation (5). Their mortality equation predicts about 1.2% mortality per year for the example stand which gives 371 trees at age 20 when the second thinning was imposed. Equations (9)-(11) were used to predict stand structure at age 20 when another 15% basal area removal was effected. The structure before and after the second thinning is shown in figure 1b. The same process was applied to obtain stand structure at ages 25 and 30 with a third thinning imposed at age 25 (fig. 2).

Stand structure at age 30 from the above thinned example was compared with structures projected for two unthinned stands (figure 2b and table 10). One of these unthinned stands was started from 500 trees per acre at age 15, as was the thinned stand; and mortality was predicted with the Clutter and Jones (1980) equation which resulted in 399 trees per acre at age 30. The other unthinned stand had 239 trees per acre at age 30, the same as the thinned stand.

The contrast between the two unthinned stands and the thinned stand at age 30 (fig. 2b) is quite reasonable. In this case, the thinned stand does not have significantly more trees in the large diameter classes (≥9 inches) than an unthinned stand of the same density. This is certainly logical in view of the type of thinning carried out. Although we have not completed an analysis to test it, a conjecture that more of the larger trees in the thinned stand will yield good quality sawlogs and veneer bolts is undoubtedly supportable.

CONCLUSIONS

Previous work with the Weibull model for unthinned plantations where equations to predict a, b, and c were developed have given rejection rates of 14% or greater with the Kolmogorov-Smirnov test. Deviations within ±0.5 inches for quadratic mean diameter have ranged from 80 to 90% (Clutter and Belcher, 1978; Smalley and Bailey, 1974a and 1974b; Lohrey and Bailey, 1976). Our tests on these data from thinned slash pine plantations lead to no rejections and 90% of the deviations were within ±0.5 inches. We therefore conclude that smooth distribution functions, such as the Weibull, can be applied quite well in modeling diameter distributions of thinned conifer plantations.

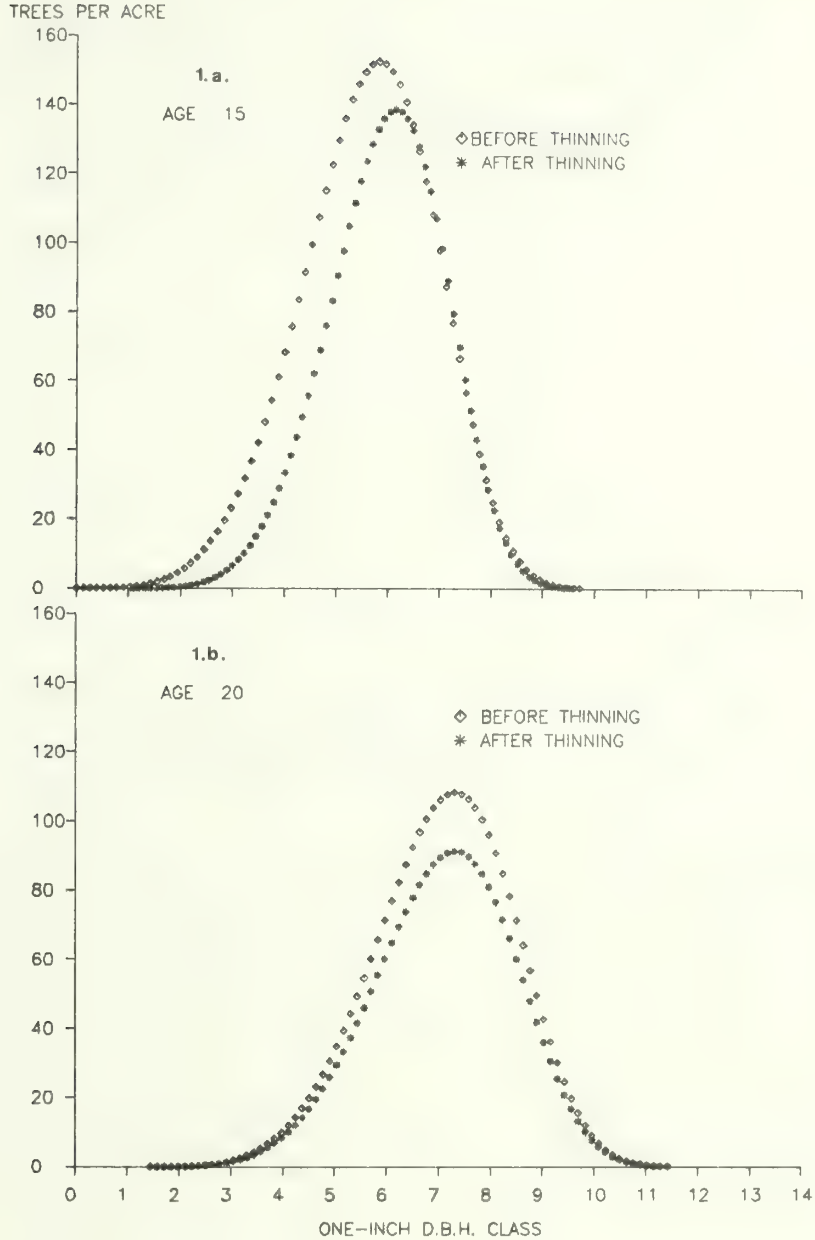

Figure 1.--Diameter distributions at ages 15 and 20. Site index is 60 feet, 15% basal area removed in thinnings, and trees per acre at age 15 was 500.

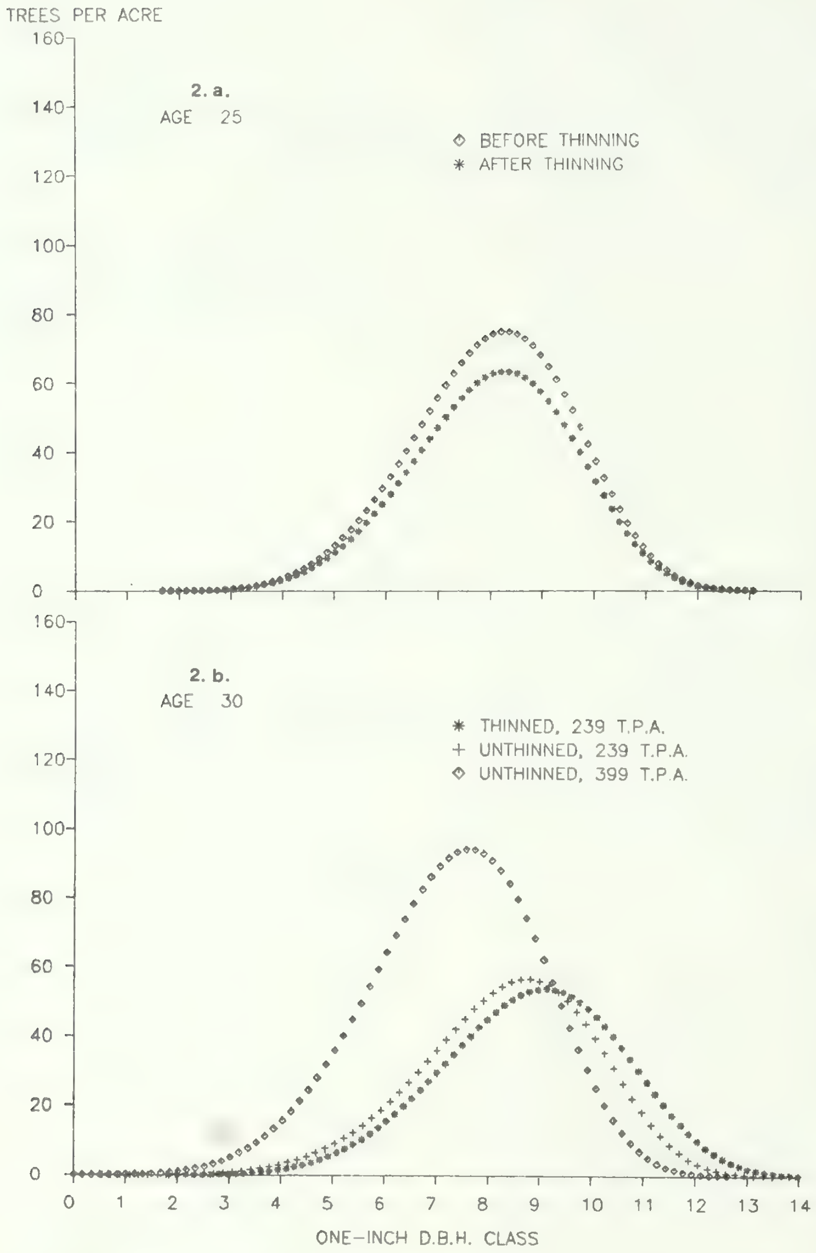

Figure 2.-- Diameter distributions at age 25 and 30. One unthinned stand at age 30 has the same density as the thinned and the other started with the same density at age 15.

Table 10.--Typical stand structure development to age 30 for a slash pine plantation on site index 60 (base age 25) having three periodic thinnings, compared with structures of two similar but unthinned plantations.

Age (years)	Trees per acre	Basal Area	Percentiles			Weibull Parameters			Mean D.b.h.
			D_{24}	D_{63}	D_{93}	a	b	c	
	-number-	sq. ft.	------inches------			--inches--			inches
Thinned Plantation									
15[1]	B: 500	92	4.7	6.2	7.4	0.0	6.1	4.947	5.8
	A: 394	79	5.2	6.4	7.6	1.1	5.3	4.946	6.1
20	B: 371	105	6.1	7.6	9.0	1.4	6.2	4.765	7.2
	A: 313	89	6.1	7.6	9.0	1.4	6.2	4.765	7.2
25	B: 297	109	6.9	8.6	10.3	1.7	7.0	4.662	8.2
	A: 251	92	6.9	8.6	10.3	1.7	7.0	4.662	8.2
30	239	106	7.6	9.5	11.3	1.8	7.7	4.583	9.0
Unthinned Plantation									
30[2]	399	123	6.2	8.5	9.7	0.0	8.0	5.017	7.5
30[3]	239	95	7.2	9.5	10.7	0.0	9.0	5.751	8.5

[1] First thinning at age 15 in stand of 500 trees per acre; "B" and "A" denote before and after each merchantable thinning which removed 15% of the standing basal area.

[2] Grown without thinning from an original stand of 500 trees per acre at age 15.

[3] Grown without thinning but having the same number of trees per acre at age 30 as the thinned stand above.

LITERATURE CITED

iley, R. L. and T. R. Dell.
1973. Quantifying diameter distributions with the Weibull function. For. Sci. 19:97-104.

nnett, F. A.
1970. Yield and stand structural patterns for old-field plantations of slash pine. USDA For. Ser. Res. Pap. SE-60. 81 pp.

nnett, F. A. and J. L. Clutter.
968. Multiple-product yield estimates for unthinned slash pine plantations -- pulpwood, sawtimber, gum. USDA For. Ser. Res. Pap. SE-35. 21 pp.

Clutter, J. L. and D. M. Belcher.
1978. Yield of site-prepared slash pine plantations in the lower coastal plain of Georgia and Florida. IN: Fries, J., H. E. Burkhart and T. A. Max (Ed.), Growth models for long term forecasting of timber yields. Vir. Poly. Inst. and State Univ., Sch. For. FWS-1-78, pp. 53-70.

Clutter, J. L. and E. P. Jones, Jr.
1980. Prediction of growth following thinning of old-field slash pine plantations. USDA For. Ser. Res. Pap. SE-217. 19 pp.

Dubey, S. D.
1967. Some percentile estimators for Weibull parameters. Technometrics 9:119-129.

Field, R. C., J. L. Clutter, and E. P. Jones, Jr.
1978. Predicting thinning volumes for pine plantations. So. Jour. of App. For. 2(2): 59-61.

Hyink, D. M.
1979. A generalized method for the projection of diameter distributions applied to uneven-aged forest stands. Ph.D. thesis, Purdue University, 161 pp.

Lohrey, R. E. and R. L. Bailey.
1976. Yield-tables and stand structure for unthinned longleaf pine plantations in Louisiana and Texas. USDA For. Ser. Res. Pap. SO-133. 53 pp.

Massey, F. J., Jr.
1951. The Kolmogorov-Smirnov test for goodness of fit. J. Am. Stat. Assoc. 46:68-78.

SAS Institute.
1979. SAS User's Guide, 1979 Edition. SAS Institute Inc., Raleigh, N. C. 494 pp.

Schreuder, H. T., W. L. Hafley, and F. A. Bennett.
1979. Yield prediction for unthinned natural slash pine stands. For. Sci. 25(1):25-30.

Smalley, G. W. and R. L. Bailey.
1974a. Yield tables and stand structure for loblolly pine plantations in Tennessee, Alabama, and Georgia highlands. USDA For. Ser. Res. Pap. SO-96. 81 pp.

Smalley, G. W. and R. L. Bailey.
1974b. Yield tables and stand structure for shortleaf pine plantations in Tennessee, Alabama, and Georgia highlands. USDA For. Ser. Res. Pap. SO-97. 57 pp.

Stiff, C. T.
1979. Modeling the growth dynamics of natural mixed-species Appalachian hardwood stands. Ph.D. Dissertation, V.P.I., Blacksburg, Va. 206 pp.

Wingo, D. R.
1972. Maximum likelihood estimation of the parameters of the Weibull distribution by modified quasilinearization. IEEE Trans. Rel., Vol. R-21:89-93.

A DIAMETER DISTRIBUTION METHOD USEFUL IN COMPATIBLE GROWTH AND YIELD MODELING OF THINNED STANDS[1/]

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Abstract.--Two growth and yield forecasting techniques have been combined to develop equations that predict the change in diameter distribution in thinned loblolly pine (Pinus taeda) plantations. The equations are based on the concept of compatible growth and yield applied to a diameter distribution model for unthinned loblolly pine plantations. This produces a generalization of the unthinned equations that projects size distribution in thinned plantations. The forecasts are compared with stand tables from a thinned plot from a spacing-thinning study located at Merryville, Louisiana.

INTRODUCTION

Diameter distribution models have been used forecast yield of unthinned plantations since eir introduction by Bennett and Clutter (1965). dels in this paper are based on a recent plication of this technique by Feduccia and hers (1979). Feduccia assumes that the equency of tree dbh is described by the Weibull nction,

$$\text{Proportion of trees} < D = 1 - e^{-\left(\frac{D-\alpha}{\beta}\right)^{\gamma}},$$

where α, β, and γ are Weibull parameters and D is an arbitrary diameter limit. All trees in the plantation are larger than α, β is a scale parameter that controls the range of diameters and γ is a shape parameter that controls the skew of the diameter distribution. The parameters are predicted from the stand variables age from planting, Ap, average height of the dominant and codominant trees, Hd, and number of surviving trees per hectare, Ts. Three prediction equations with the same functional form but different coefficients (bo, b1, b2 and b3) are used to predict the three parameters, namely

$$\alpha, \beta \text{ or } \gamma = bo + b1 \log(Ap) + b2 \log(Hd) + b3 \log(Ts).$$

These equations can be generalized to forecast size distribution of thinned plantations by applying compatible growth and yield concepts developed by Clutter (1963) and later refined by Moser and Hall (1969). Moser and Hall defined the first derivative of yield, Y(A), with respect to age, A, as growth rate, y(A), namely

$$dY(A)/dA = y(A).$$

The change in yield or growth over the period

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, Nvember 6-7, 1980.

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Ao to A1, $\Delta Y(Ao \text{ to } A1)$, is

$$\Delta Y(Ao \text{ to } A1) = \int_{A0}^{A1} y(A)dA = Y(A1) - Y(A0)$$

These concepts can be generalized to describe changes in Weibull parameters.

GROWTH OF WEIBULL PARAMETERS

The growth rate of a Weibull parameter can be defined in the same way Moser and Hall described growth of forest stands. The growth rate, p(A), of the Weibull parameter, P(A), is

$$dP(A)/dA = p(A).$$

The change in the Weibull parameter or growth over the period A0 to A1, $\Delta P(A0 \text{ to } A1)$ is

$$\Delta P(A0 \text{ to } A1) = \int_{A0}^{A1} p(A)dA = P(A1) - P(A0).$$

Applying this to the equations from Feduccia and others (1979) results in

$$\Delta P(A0 \text{ to } A1) = b1[\log(A1)-\log(A0)] +$$

$$b2[\log(H1) - \log(H0)] + b3[\log(T1) - \log(T0)],$$

where H0 and H1 are dominant heights at A0 and A1 and T0 and T1 are trees per hectare at A0 and A1. This set of equations can be used to update inventory information. If H0, T0, and the Weibull parameters are known from measurements of an existing stand and H1 and T1 are forecast from site index curves and survival curves, Weibull parameters at A1 can be forecast by adding $\Delta P(A0 \text{ to } A1)$ to the Weibull parameters at A0. These forecast Weibull parameters can be used to describe the stand table at A1.

GROWTH OF WEIBULL PARAMETERS IN THINNED PLANTATIONS

The same set of equations can be used to forecast stand tables in thinned plantations. The only difference is that T0 and T1 are reduced due to the thinning. This results in greater shifts to the right of the stand table, and hence faster diameter growth in thinned stands. This procedure for forecasting stand tables was compared with data from three thinning studies located in Louisiana.[1] This comparison indicated that the thinned plantations grew slightly faster than the equations forecast. A correction factor based on age at the first thinning intervention, TA, and residual basal area per hectare for the first thinning, TB, was added to the growth equation for the α parameter to account for the difference in estimated and observed diameter growth rates. The correction factor was determined by regressing the difference between observed and estimated α parameter on a set of stand variables including TA and TB. The final form of the correction factor, CF(A0 to A1), is

$$CF(A0 \text{ to } A1) = [1.7541 - 0.0033148 \cdot TA \cdot TB] \cdot$$

$$[A1 - A0].$$

Use of the correction factor results in slightly faster growth rates in plantations thinned heavily at young ages.

The use of this procedure for estimating growth of thinned stands is illustrated with data from plot 54 of the Merryville Thinning Study.[2] The plot was planted at a 3 x 3 meter spacing and is site index 21 meters on a 25 year base. Figure 1 shows the stand table and Weibull diameter distribution for the plot at 17 years after planting and thinning to 14 square meters per hectare. The parameters of the diameter distribution were estimated with maximum likelihood procedures from the stand table data.

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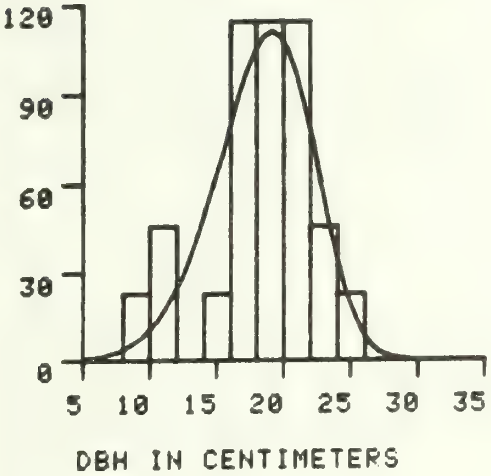
[1] Unpublished Forest Service progress reports describe these three studies.

Feduccia, D. P. 1974. Thinning in a loblolly pine spacing plantation. U. S. Forest Service Progress Report 4110-FS-SO-1102-3.1, 132 p.

Feduccia, D. P. and W. F. Mann, Jr. 1975. Effect of site, initial spacing, and thinning intensity on growth of planted loblolly pine. U. S. Forest Service Progress Report 4110-FS-SO-1102-3.22, 177 p.

Feduccia, D. P. 1976. Row vs. selective thinning for planted slash and loblolly pine. U. S. Forest Service Progress Report 4110-FS-SO-1102-3.33, 126 p.

[2] Data from this study is described in Feduccia, D. P. and W. F. Mann, Jr. 1975. *Op. Cit.*



ure 1.--Stand table and diameter distribution 17 years after planting and thinning to 14 m^2/ha.

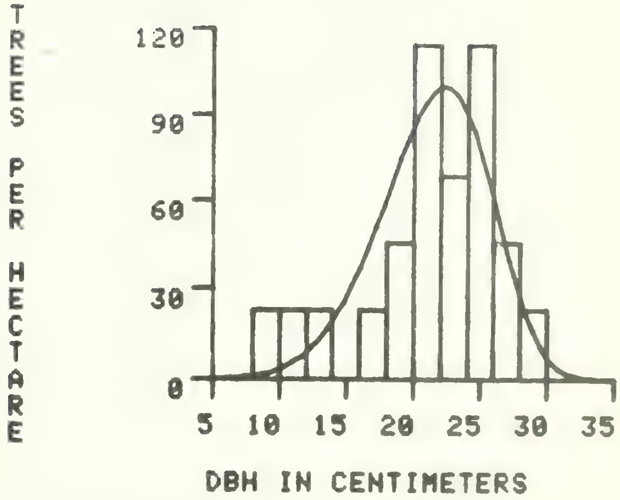


Figure 2.--Stand table and diameter distribution 22 years after planting.

Weibull parameter growth equations were
d to forecast the diameter distribution
22 years from planting. The results of
s forecast and the observed stand table
presented in Figure 2. The forecasting technique worked reasonably well on this plot.

SUMMARY

Equations for projecting changes in diameter distribution in thinned and unthinned plantations have been developed. When used in combination with site index curves, survival curves, individual tree volume equations and height from dbh curves they can be used to estimate yield and size distribution of various thinning regimes and to update forest inventory information.

LITERATURE CITED

Clutter, Jerome L.
1963. Compatible growth and yield models for loblolly pine. Forest Science 9:354-371.

Clutter, Jerome L. and Frank A. Bennett.
1963. Diameter distributions in old-field slash pine plantations. Georgia Forest Research Council Report No. 13, 9 p.

Feduccia, D. P., T. R. Dell, W. F. Mann, Jr., T. E. Campbell and B. H. Polmer.
1979. Yields of unthinned loblolly pine plantations on cutover sites in the west gulf region. U. S. Forest Service Research Paper SO-148, 88 p.

Moser, John W. and Otis F. Hall.
1969. Deriving growth and yield functions for uneven-aged forest stands. Forest Science 15:183-188.

A THINNING RULE FOR SLASH PINE PLANTATIONS

ON A MEDIUM SITE[1]

F. Thomas Lloyd and Earl P. Jones, Jr.[2]

Abstract.--Target, after-thinning, residual densities that produce near maximum periodic growth of slash pine plantations are determined for medium sites with an average height at age 25 of 63 feet. This was done by fitting net 5-year growth (in pounds of dry wood per acre) to the corresponding values of Stahelin's percent stocking obtained from unthinned stands covering a wide range of densities. This approach is based on the assumption that the growth of the thinned stand will quickly recover to that of an unthinned stand of the same percent stocking. The stand ages at which thinnings should be made were also established. This age is defined as the point where the annual accretion of what would be the yield from a first thinning begins to decrease.

INTRODUCTION

Growing space is a leading factor in control-
ig the growth rate of individual trees. The
ice of planting spacing and the timing and in-
sity of thinning offers foresters who manage
sh pine plantations two methods of controlling
s determinant of tree growth. Much has been
lished about the effects of the planting spacing
yield, but very little on the interrelationship
ween initial spacing and subsequent thinning
edules.

A defendable strategy for pulpwood production
to maximize total net growth (i.e., growth of
viving trees minus mortality) from a site over
rotation. This is accomplished by thinning as
quently as is economically possible in such a
as to salvage potential mortality and maintain
stand at near full occupation of the site. The
blem is that measurement of net growth is both
tly and subject to large error. What we do then
calibrate more easily observed or measured stock-
attributes with net growth and use the stocking
sure as the control variable. Stahelin's (1949) stocking percent is used in this study because it is easily obtained by using an angle prism, does not depend on age and site quality, and has been successfully applied to thinned stands of natural slash pine (Gruschow and Evans 1959). The goals of this work are 1) to estimate target residual densities and ages of the first thinnings for plantations resulting from a wide range of planting densities on a medium slash site and 2) to hypothesize stocking guides as to when to initiate first thinnings in these slash pine plantations.

SOURCE OF DATA

These data come from a study established by the Southeastern Forest Experiment Station in 1952 on the Holt Walton Experimental Forest in the middle Coastal Plain region of Georgia. Seedlings were planted at 8 spacings: 15 x 15, 7.5 x 15, 10 x 10, 6 x 12, 8 x 8, 5 x 10, 6 x 8, and 6 x 6 feet. Three-quarter-acre spacing plots were randomly assigned in each of two complete blocks, and the entire study was installed in an old field which had last been cultivated the previous year. Harms and Collins (1965) observed that with good soil moisture conditions and care in handling and planting the seedlings, 97 percent survival at age 4 resulted--much better than average, with each spacing plot as fully stocked as could be expected. Starting at age 10, measurements for each plot consisted of a complete diameter tally and a random sample of heights on at least 20 trees distributed evenly over the diameter classes. These measurements were taken annually from age 10 through age 22 and again at age 25.

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[1] Paper presented at Southern Silvicultural
earch Conference, Atlanta, Georgia, November
, 1980.

[2] Authors are Research Foresters, USDA Forest
vice, Forestry Sciences Laboratory, Charleston,
29407, and Southern Forest Fire Laboratory,
on, GA 31208, respectively.

PROCEDURES

The diameter and height measurements on the two plots for each spacing were combined into a composite plot and converted to yield (in pounds) of total stem dry weight (i.b.) per acre (Queen and Pienaar 1977). Weight was used instead of volume because we wanted total yield to a 2-inch diameter class and a volume table for this range of diameters was not available when the analysis started, and because the use of pulpwood weight is extensive. These computations resulted in 112 stand tables and yield observations (eight spacings each measured 14 times). Each spacing yielded nine 5-year net growth values for the growth periods 10 to 15, 11 to 16,..., 17 to 22, and 20 to 25 years. We chose the 5-year growth period because it represents the practical minimum time between thinnings. Also, the coefficient of variation for growth becomes prohibitively large for periods shorter than five years. The first step was to relate these increments of net periodic growth to some measure of stocking.

Gruschow and Evans (1959) successfully used Stahelin's (1949) percent stocking as a predictor of periodic growth of thinned natural stands of slash pine. They chose not to use basal area alone because at theoretical full stocking it varies widely with site and age. In addition, because of our range of 1000 seedling per acre at planting, we wanted a stocking measure that reflected increasing basal area for the same stocking level as the number of trees per acre decreased. Figure 1 illustrates how these data approach and then follow Stahelin's 100 percent curve for the two densest spacings.

The decision of when to thin depends on the target stocking because a greater percentage of volume is removed to obtain the lower residual densities. Therefore, the first step in this analysis concerned establishing a range for residual stocking that produced near maximum periodic growth. This was done by combining the data from all spacings and then studying the relation of 5-year net growth to Stahelin's (1949) percent stocking. This is based on the assumption that periodic growth of a thinned stand will be close to that of an unthinned stand with the same percent stocking. A point of maximum growth was expected to be contained in these data because of the wide range of planting densities.

The stand age at the first thinning from below varies with planting spacing and, as discussed earlier, probably with the target residual stocking. We estimated this stand age as that point in stand development where the annual increase in the weight of the first thinning begins to decline. We approximated the yields for the first thinning at each age by removing trees one at a time from the observed stand tables until the target residual density was reached. The onset of declining thinning yield is estimated as the point of inflection for a model expressing the above defined thinning yield as a function of stand age. These removed yields are only approximations to real thinnings because diameter distributions do not contain information about spacial distributions of the residual stands, but because we are removing the smallest trees, the outcome of actual thinnings should not differ greatly.

For a given planting spacing, the age of maximum accretion in the first thinning yield will increase with decreasing plantation survival, so although these ages can be used to compare the timing of the first thinning under the uniform conditions of this study, they do not offer useful guidelines for field applications. However, if either percent stocking or basal area values corresponding to these ages are stable, then a genera thinning rule is suggested. This is our approach to satisfying the second objective.

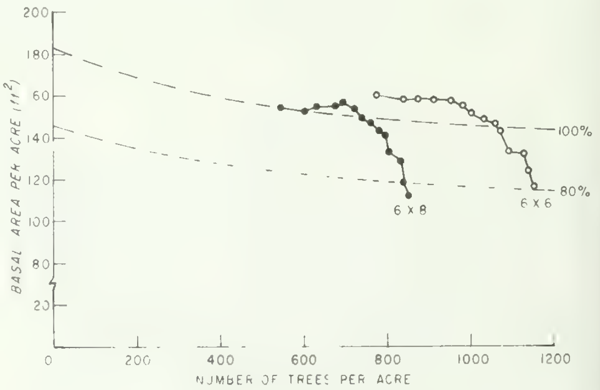

Figure 1.--The basal area and number of trees per acre for the 6 x 8 and 6 x 6 spacings plotted with Stahelin's 100 and 80 percent stocking curves.

RESULTS

The nine periodic growth and percent stockin values were combined for the eight spacings (72 observations) and plotted (fig. 2, see last page. The mean relationship was adequately described with the quadratic equation: periodic growth = 5332.47 + 833.556 (% stocking) - 6.86355 (% stocking)^2. The R^2 value of the model is 0.44. The large variation is explained in part by the inherent variability in growth due to measurement error, as well as variation resulting from the spacing plots. Maximum net growth from this equation occurs at 60 percent stocking which (as was anticipated) is inside the observed stocking range. The following predictions from this equation (rounded to the nearest 100 lbs.)

lustrate the declining rate of periodic growth r stocking above 80 percent:

Percent stocking	Lbs/acre
40	27,700
50	29,900
60	30,600
70	30,000
80	28,100
90	24,800
100	20,100
110	14,000

uschow and Evans observed that the rate of inease for percent stocking was low in the lightly d heavily stocked stands and tended to be greatt at the 40 to 50 percent levels. This observaon was substantiated by our data, so residual vels of 60 percent, 50 percent, and 40 percent ocking were used to investigate the question of en to thin. As with Gruschow and Evans' work with tural slash pine, we expect the percent stocking vels for maximum growth to be higher for plantaons on better sites, but were unable to investie site effects in this study.

The estimated ages of thinning for these plots e shown in table 1 for residual stockings of 60, , and 40 percent. The growth rate of thinning eld culminates before age 10 for the two densest acings. The effect of planting spacing on age of rst thinning is large, while the effect of resid- stocking on thinning age is only a 1-year rection for each 10 percent reduction in residual ocking. The residual basal areas are not conant, but range from 10 to 15 ft.^{2} across the tial spacing range. This outcome fits Reineke's 933) result which shows basal area for a given ocking level to be proportional to the inverse number of trees per acre. The standing basal eas and corresponding percent stockings at the edicted thinning ages for residual stockings of , 50, and 40 percent are shown in table 2. The erage standing basal area values suggest to thin 60, 50, and 40 percent stocking when basal area aches 119, 112, and 107 ft.^{2}, respectively.

We have included raw data in table 3 for the rson interested in viewing the analysis from her angles. The problem of extreme variation in nual growth is clear if yearly differences are puted, for by using these differences it is dif- ult to determine with any degree of certainty optimum thinning age as defined. However, ic functions of time using all thinning yields r a given spacing and residual percent stocking e R^2's greater than 0.99, and therefore give cise estimates of average net growth for any age the observed age range and good estimates of the nt of inflection. The sums (i.e., total yields) of the pairs of numbers for each age and planting spacing is the same (within rounding error) for all residual percent stockings, but the thinning component accounts for a larger percent of the total as residual stocking decreases. The magnitude of thinnings in table 3 also gives information about the economic feasibility of first thinnings at various ages.

Table 1.--Estimated age for thinning in eight planting spacings to achieve three selected residual stock densities expressed as Stahelin's percent stocking

Planting spacing	Thinning age	Trees per acre at thinning	Basal area after thinning	Trees after thinning
ft	yr	no	ft^2	no
RESIDUAL DENSITY: 60 PERCENT STOCKING				
15 x 15[1/]	>25	<161	>101	
7.5 x 15	19	339	97	240
10 x 10	17	367	96	269
6 x 12	16	507	94	343
8 x 8	13	642	92	421
5 x 10	12	819	90	538
6 x 8[1/]	<10	>850	<90	
6 x 6[1/]	<10	>1152	<87	
RESIDUAL DENSITY: 50 PERCENT STOCKING				
15 x 15[2/]	21	165	84	128
7.5 x 15	17	347	81	217
10 x 10	16	374	80	223
6 x 12	14	520	78	303
8 x 8	12	651	77	366
5 x 10	11	826	75	482
6 x 8	<10	>850	<75	
6 x 6	<10	>1152	<72	
RESIDUAL DENSITY: 40 PERCENT STOCKING				
15 x 15[2/]	21	165	67	97
7.5 x 15	16	349	61	173
10 x 10	15	376	64	182
6 x 12	13	523	63	250
8 x 8	11	652	61	302
5 x 10	11	826	60	372
6 x 8	<10	>850	<60	
6 x 6	<10	>1152	<58	

[1/] Annual growth rate in thinning yield culminates outside the observed age range (10 to 25 years).

[2/] Values supported by limited number of data points.

Table 2.--The age, basal area, and percent stocking before thinning for five planting spacings to be thinned to residual densities of 60, 50, and 40 percent stocking

Planting spacing[1/] (ft)	Residual Percent Stocking								
	60			50			40		
	Thinning age	Basal area	Stocking	Thinning age	Basal area	Stocking	Thinning age	Basal area	Stocking
	yr	ft^2	percent	yr	ft^2	percent	yr	ft^2	percent
7.5 x 15	19	118.9	74	17	109.5	68	16	105.1	65
10 x 10	17	117.7	73	16	114.7	72	15	109.1	68
6 x 12	16	119.3	76	14	112.4	72	13	105.9	68
8 x 8	13	120.1	78	12	114.1	74	11	104.3	68
5 x 10	12	119.3	79	11	110.6	74	11	110.6	74
Mean		119	76		112	72		107	69

[1/] The 15 x 15, 6 x 8, and 6 x 6 spacings are not included because maximum annual growth rate in thinni yield occurs outside observed age range of 10 to 25 years.

CONCLUSIONS

Maximum periodic growth in total stem wood (i.b.) on average slash pine sites (63 feet, base age 25) is maintained by thinning when basal area reaches 119, 112, and 107 $ft.^2$ for residual stockings of 60, 50, and 40 percent, respectively. These guides should apply for several subsequent thinnings, but we are not able to test this assertion with these data. The choice of residual stocking will depend on how frequent subsequent thinnings will be made and how much is needed to be economically feasible. The 40-percent residual stocking leaves a light basal area, but the net periodic growth following this intensity of thinning is 90-percent of the maximum and the growth is increasing. Another point illustrated by these data is that target residual basal area is not constant but, rather, increases as the residual number of trees decreases. As expected, the age at time of thinning decreases as planting density increases, but will vary with plantation survival, so the decision when to thin should be determined by periodically checking standing basal area.

LITERATURE CITED

Gruschow, G. F., and T. C. Evans.
1959. The relation of cubic-foot volume gro to stand density in young slash pine stands For. Sci. 5:49-55.

Harms, William R., and Arthur B. Collins III.
1965. Spacing and twelve-year growth of sl pine. J. For. 63:909-912.

Queen, William R., and Leon V. Pienaar.
1977. Green and dry stem weight equations site-prepared slash pine plantations in th Coastal Plain of Georgia and North Florida Univ. Ga., Schl. For. Resour. Res. Pap. 1, 58 p. Athens.

Reineke, L. H.
1933. Perfecting a stand-density index for even-aged forests. J. Agric. Res. 46:627-638.

Stahelin, R.
1949. Thinning even-aged loblolly and slas pine stands to specified densities. J. Fo 47: 538-540.

able 3.--Weight of yield removed in thinning (lower value) and left in residual stand (upper value) for theoretical thinnings applied at ages 10 through 22 and age 25, in eight spacings reduced to residual densities of 60, 50, and 40 percent stocking

100 pounds

RESIDUAL DENSITY: 60 PERCENT STOCKING

Age (years)	Planting spacing (feet)							
	15x15	7.5x15	10x10	6x12	8x8	5x10	6x8	6x6
10	147	247	264	300	304	291	307	291
	0	0	0	0	6	39	70	85
11	182	289	312	329	323	324	325	314
	0	0	0	0	35	63	98	118
12	237	373	387	387	369	358[1/]	368	347
	0	0	0	35	83	102	150	163
13	272	411	438	417	402[1/]	382	401	350
	0	0	7	47	110	119	177	170
14	343	497	491	459	459	424	448	408
	0	6	38	79	153	155	223	233
15	380	533	533	499	499	460	472	437
	0	29	62	103	182	176	249	256
16	430	569	567	514[1/]	519	486	498	455
	0	41	99	120	213	209	272	277
17	470	593	586[1/]	534	537	496	516	474
	0	66	115	137	234	222	284	298
18	543	637	619	562	561	534	545	508
	0	99	159	180	289	269	332	338
19	609	668[1/]	661	607	594	565	580	519
	0	131	186	209	315	289	358	362
20	665	695	689	623	619	588	614	549
	0	154	227	216	337	303	371	375
21	702	714	711	647	654	612	643	571
	0	179	254	237	361	313	373	377
22	741	734	737	649	671	633	657	589
	0	200	248	250	343	297	373	388
25	830	792	785	728	736	683	715	624
	73	264	310	289	377	330	404	406

100 pounds

RESIDUAL DENSITY: 50 PERCENT STOCKING

Age (years)	Planting spacing (feet)							
	15x15	7.5x15	10x10	6x12	8x8	5x10	6x8	6x6
10	147	247	264	271	257	245	258	248
	0	0	0	29	53	85	119	128
11	182	289	297	280	273	272[1/]	273	264
	0	0	15	48	85	115	150	167
12	237	351	338	327	309[1/]	302	310	291
	0	22	48	95	144	158	208	218
13	272	368	372	352	337	321	335	294
	0	43	73	112	175	179	243	226
14	343	422	413	385[1/]	386	358	375	344
	0	81	116	153	226	221	296	297
15	380	449	447	422	421	385	396	369
	0	112	148	181	260	251	324	325
16	430	478	476[1/]	433	438	407	419	385
	0	131	189	201	294	288	351	347
17	470	498[1/]	495	448	454	417	435	399
	0	160	206	223	318	301	365	372
18	535	538	518	471	469	449	462	425
	8	198	260	271	380	353	415	421
19	572	563	554	510	496	476	485	437
	37	237	292	307	412	378	452	444
20	593	584	581	525	520	498	515	462
	71	265	336	314	436	393	470	463
21	617	600	599	544	551	517	540	480
	85	292	365	340	464	408	476	468
22	642	618	621	542	566	534	552	497
	99	316	365	357	448	395	479	480
25	701	668	657	610	617	577	605	530
	202	387	437	407	496	435	514	501

Table 3.--Continued

Age (years)	Planting spacing (feet)							
	15x15	7.5x15	10x10	6x12	8x8	5x10	6x8	6x6
	100 pounds							
	RESIDUAL DENSITY: 40 PERCENT STOCKING							
10	147	227	226	221	207	196	207	203
	0	20	39	79	103	133	170	172
11	182	242	240	228	224[1]	220[1]	221	212
	0	47	72	101	134	167	202	219
12	237	285	275	262	247	246	250	234
	0	88	112	160	206	214	269	275
13	272	297	300	286[1]	271	259	270	238
	0	114	145	179	241	241	308	282
14	332	341	330	312	311	287	303	279
	11	162	198	226	301	292	369	361
15	364	363	361[1]	341	341	310	320	300
	16	198	234	262	339	326	401	394
16	387	388[1]	385	349	352	328	340	309
	43	221	281	285	380	367	430	423
17	409	402	398	361	364	337	354	321
	61	256	303	311	408	381	447	450
18	438	432	419	380	377	365	372	342
	105	304	359	362	472	437	506	504
19	466	456	448	413	400	385	391	352
	143	343	398	404	509	470	547	529
20	481	472	468	424	422	402	414	374
	184	377	449	415	534	489	570	551
21	501	482	482	438	446	416	439	389
	201	411	482	446	569	509	577	559
22	518	496	502	436	459	431	448	406
	223	438	484	464	555	498	582	572
25	566	540	533	494	499	469	487	426
	337	515	561	523	614	543	632	605

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[1] Culmination of annual growth in thinning yield.

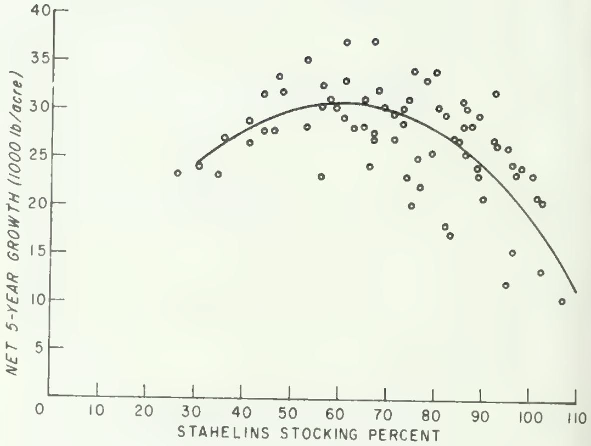

Figure 2.--Net 5-year growth in pounds for total stem dry weight and percent stocking points with the fitted quadratic function used to estimate the stocking level with maximum growth.

THINNING OPPORTUNITIES IN THE MIDSOUTH
DURING THE 1980'S [1]

Charles E. Thomas

and

Mary S. Hedlund [2]

Abstract.--Plantation acreages in the Midsouth states have increased substantially during the past twenty years. Many of these acres will first reach commercial thinning age during the coming decade. Volumes, in pine only, on surveyed plantations indicate that serious attention must be paid to the incroachment of hardwoods if the optimistic expectations of published growth and yield estimates are to be realized. Volumes available from the portion of basal area greater than 60 square feet per acre are reported for surveyed locations in Mississippi.

Pine plantations, represent the hope and vestment of the forest industry in the South. her sources of timber are likely to be less oductive and the product lower in quality. nsiderable research resources have been devoted describing and modeling the potential returns om intensive management of southern pine antations. Unfortunately, most of these studies ve been case studies emphasizing the better ands and their yields. In the past there has en little attempt to summarize the current state plantations or to forecast production returns om existing stands over a wide area. Extensive ea reports, such as the Forest Statistics of the S., 1977, made no attempts to delineate antations from the total resource in the ojections of timber supply. This paper attempts give an overview of the acres and volumes kely to be available for commercial exploitation ring the decade of the 80's in the seven dsouth states.

Two aspects of the thinning opportunities will examined. First, the acreages available - their stribution in time and geography - will be ported. Second, a sketch of the volumes and basal eas currently found in two specific states ssissippi and Louisiana) will be reviewed. Based the findings for example states, implications r the total resource of the Midsouth will be made.

Two sources of information were used to obtain the numbers of acres in plantations. The first is the U.S. Forest Service planting record. Each year the Forest Service releases a report showing acres of Forest Planting and seeding, by state and ownership class. The Midsouth still trails the Southeast in total acres planted with about 13 million acres as of fiscal year 1978. These planting record acreages (which are apt to overestimate true acreage) were compared to Southern Forest Experiment Station state inventory estimates of plantation acreage. Totals for all states and for the most recent 10-year interval in two states (Arkansas and Mississippi) were compared. The inventory findings alone are apt to be conservative. In the Midsouth the percentage of inventoried plantations to planted acres consistently shows between 70 and 80 percent of the plantation acreage reported in the planting records. Using a 20 percent reduction factor on the reported acres yields about 10 million acres of plantation in the seven states. This figure is about 33 percent of the 30 million acres of commercial forest presently considered pine type in the Midsouth.

Figure 1 illustrates the trend in plantings over a 25-year period. The trend for Midsouth states is somewhat different from that found in the Atlantic South. There a clear, nearly linear trend was established in the 50's. Even after the planting expansion during the Soil Bank Program, forest industry continued to increase the acres planted almost yearly. Our experience is different. After the brief expansion of planting during the late 50's, planting generally returned to the levels of the earlier part of the decade and remained at that level until the late 1960's. Total acres planted did not regularly exceed 400,000 per year until after 1970. At the state level the ages of plantations and acreages involved reveals an additional trend, the westward movement of forest management practices. Figures 2 - 5 show the onset of plantation establishment in several of the states. The oldest significant plantation acreages are those of Alabama, while the youngest are to be found in Texas and Arkansas. Only in the last five years have significant acres of plantation been established in Arkansas; these will not become suitable for commercial thinning until well into the 1990's.

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[1] Paper presented at Southern Silvicultural search Conference, Atlanta, Georgia, November 6-7 1980.

[2] Research Forester and Mathematician, spectively, USDA-Forest Service, Southern rest Experiment Station, New Orleans, La.

The distribution of pine plantation is almost evenly divided in quarters among Alabama, Mississippi, Louisiana and the remaining four states of the Midsouth (Figure 6). For the next 10 years significant acreages suitable for thinning will come from the three Gulf Coast states.

In Louisiana there are many fewer acres of plantation inventoried than appear in the plantation record. During the ten year interval preceding the last inventory of the states forest less than 60% of the acres reported in the plantation record were discovered. This is a major departure from the pattern and percentage found in other midsouth states. A similar percentage of acres was found to have been established during the 10 year interval which began in 1952.

The next two figures (7 and 8) portray the ownership classes of commercial forest land in the region. Figure 7 is the overall ownership pattern indicating that industry owns nearly 20 percent of the 188 million acres reported in Forest Statistics of 1977. Seventy two percent of the acreage is owned by NIPF's (Non-Industrial Private Forest owners). In terms of plantations Forest Industry has nearly 50 percent of the reported acres planted, while only 38 percent of these acres are NIPF (Figure 8). (National Forest and other public owners represent less than 10 percent of the plantation acres). Many of the NIPF acres of plantation can be attributed to the Soil Bank Program. Forest survey data indicated significant shifts in land use between the two most recent surveys. Examination of the survey data did not reveal the specific disposition of Soil Bank era acres. Some certainly reverted to agricultural use, others remain in plantation. Because many of these Soil Bank-NIPF acres are now biologically ready to be thinned, disposition of these plantation acres will receive some attention in upcoming surveys.

The age distribution of existing pine plantations was determined from the planting data. Figure 9 shows percentage distribution of the data in 5-year age classes over the 10 million acres planted. Again the largest concentration is in the 20-year old class, those established under Soil Bank aegis. The second largest class is the recent planting (5-year-old class). Recall from Figure 4 that some of these young plantings are on poor shortleaf sites in the western part of the region and they will probably require longer to reach a commercially thinable density and volume.

The acreage of thinning opportunity in the Midsouth during the decade ahead is illustrated in Figure 10. Unlike the Southeastern area trend, a more pronounced upward trend in acres is noticeable. The number of acres planted in 1965 was less than 250,000, and when discounted for the acres observed in our state inventories this amounts to 200,000 acres that should be available for thinning. However, by the end of the period an annual thinning potential on nearly 600,000 acres could exist in the Midsouth. In the relatively short space of 10 years a three-fold expansion in the numbers of acres will require commercial thinnings, if the optimistic estimates of production under intensive management are to be realized. Such an increase could easily require technological or systems changes, thus it would be well to begin planning now for this development.

A second consideration in the region is the timing of the availability. A comparison of the years in which plantings began to increase noticeably shows clearly the movement east to west. It should not be surprising that significant acreages reach commercial thinning densities and volumes in Alabama and Mississippi earlier than in Louisiana, Texas, and Arkansas. This state-by-state trend does have something of mitigating influence on the overall increases, but in some cases it could mean that the time to plan is already slipping past - as in Alabama. This problem of acrages available for thinning, deserves considerable attention by the states and private industry now.

Originally it was our intentions to estimate potential thinning volumes in pine plantations fo the entire Midsouth. Time and data access limite

FIGURE 1. ACRES OF FOREST PLANTING
MIDSOUTH TOTALS BY OWNERSHIP

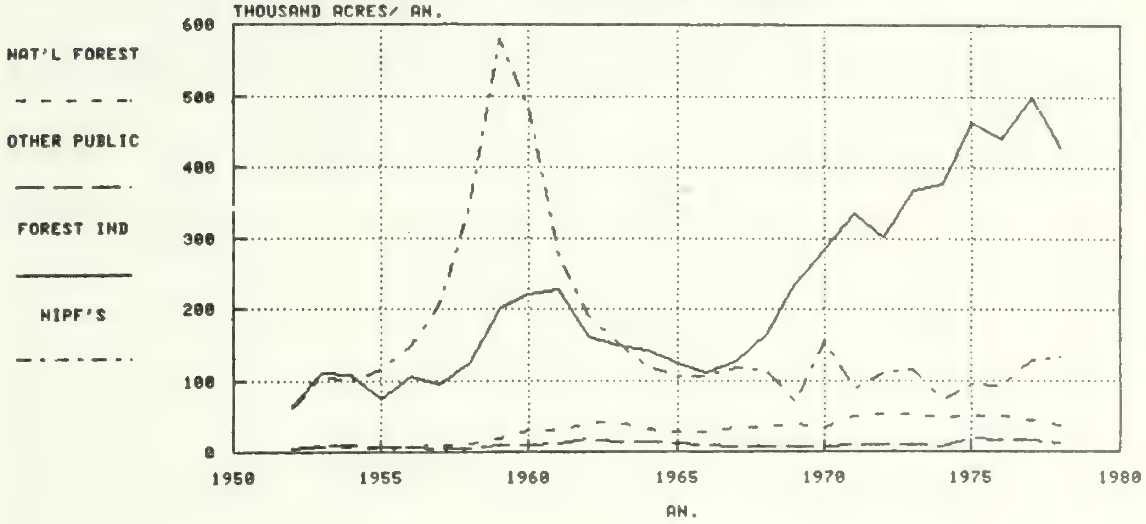
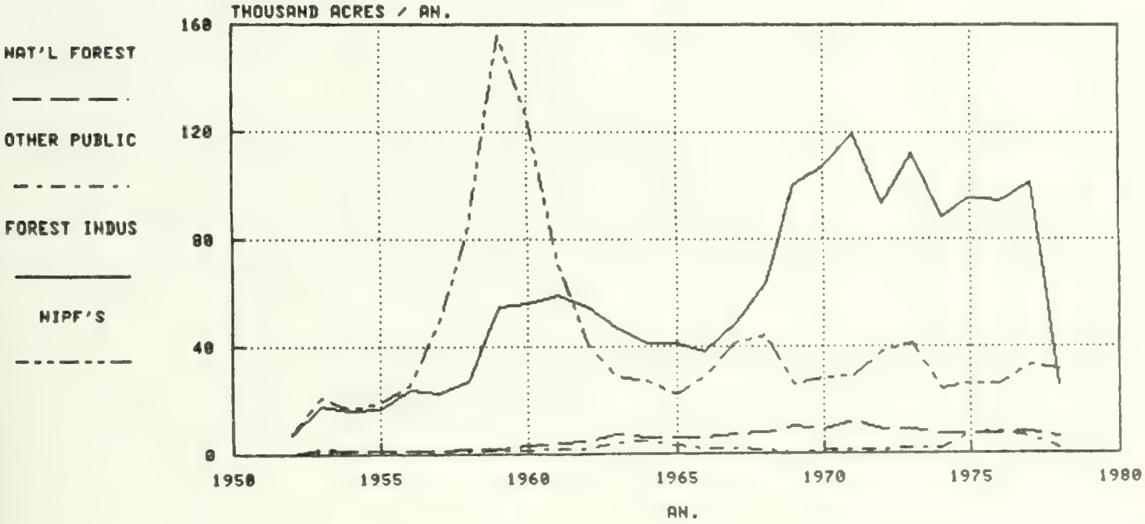


FIGURE 2. ACRES OF FOREST PLANTING
ALABAMA: BY OWNERSHIP



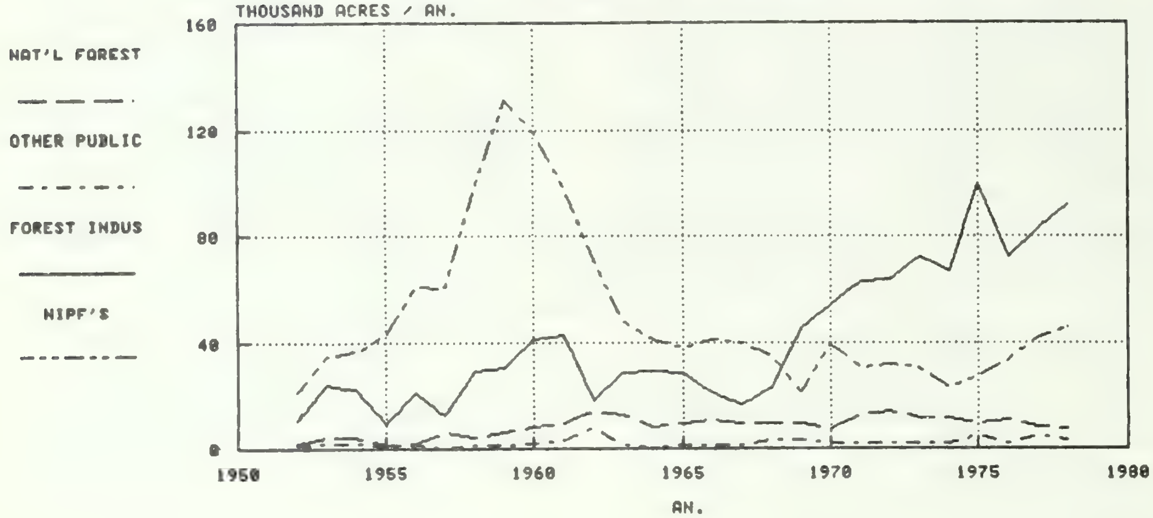


FIGURE 3. ACRES OF FOREST PLANTING

MISSISSIPPI: BY OWNERSHIP

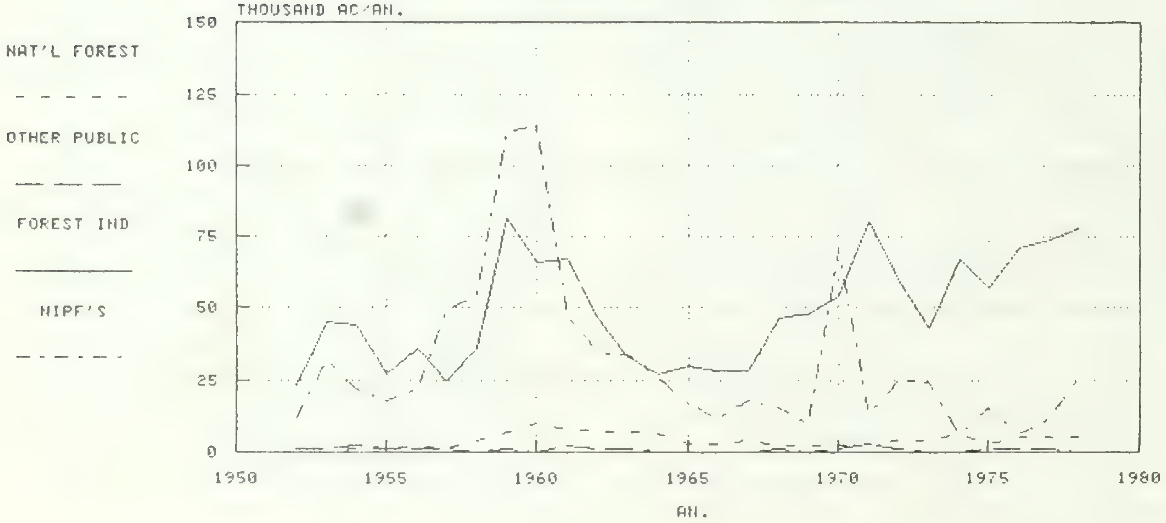


FIGURE 3a. ACRES OF FOREST PLANTING

Louisiana: by ownership class

FIGURE 4. ACRES OF FOREST PLANTING

ARKANSAS: BY OWNERSHIP

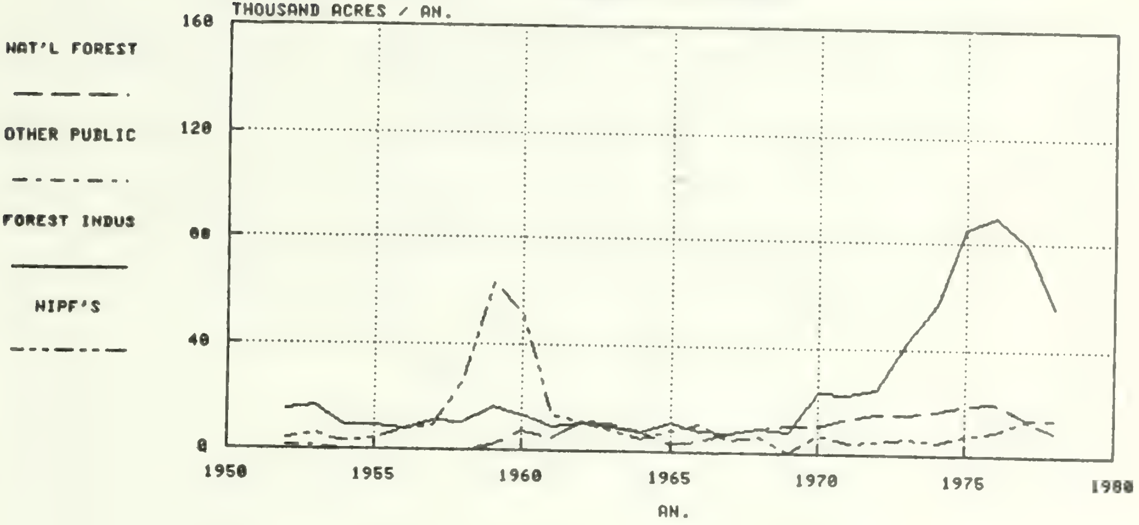


FIGURE 5. ACRES OF FOREST PLANTING

TEXAS: BY OWNERSHIP

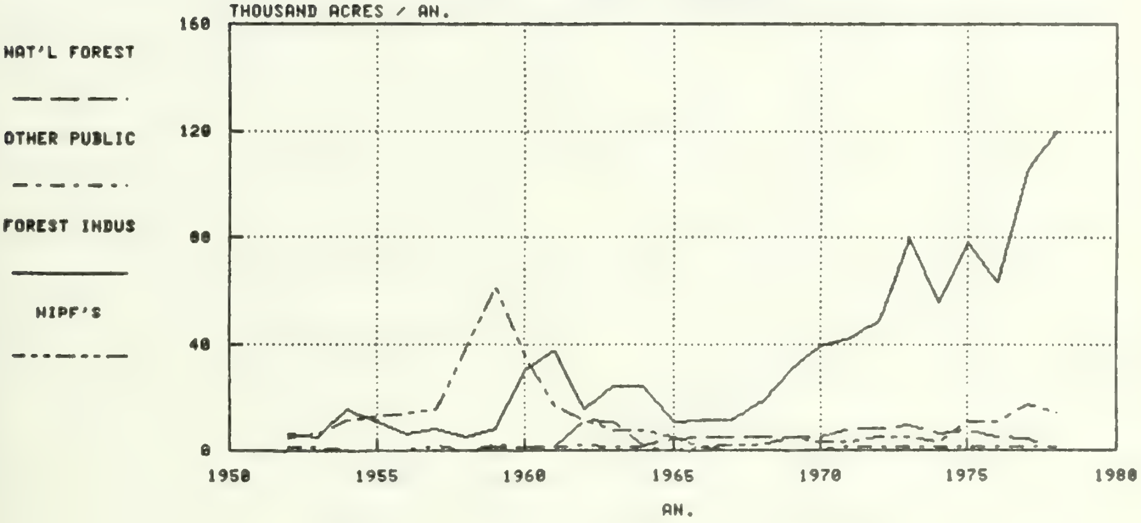
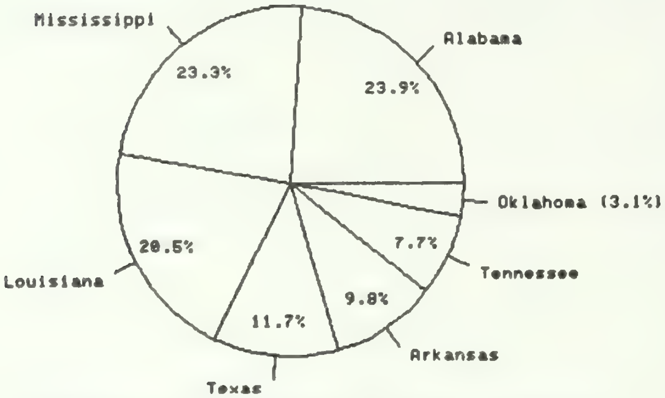
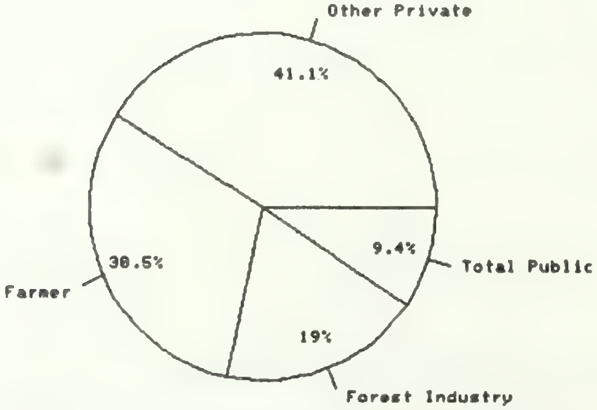


FIGURE 6. PLANTATION ACREAGE
Midsouth States



Based on 10 million acres

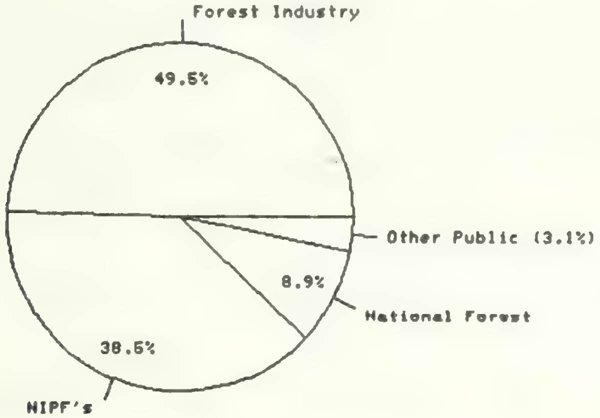
FIGURE 7. OWNERSHIP OF COMMERCIAL FOREST
Midsouth States



Based on 188 million acres

FIGURE 8. OWNERSHIP OF PLANTATION

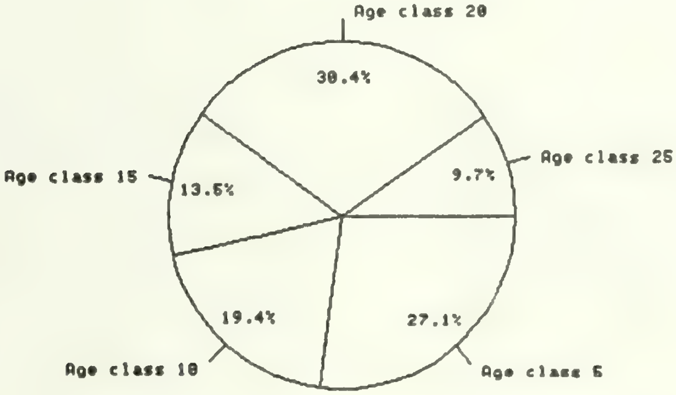
Midsouth States (1978)



Based on 10 million acres

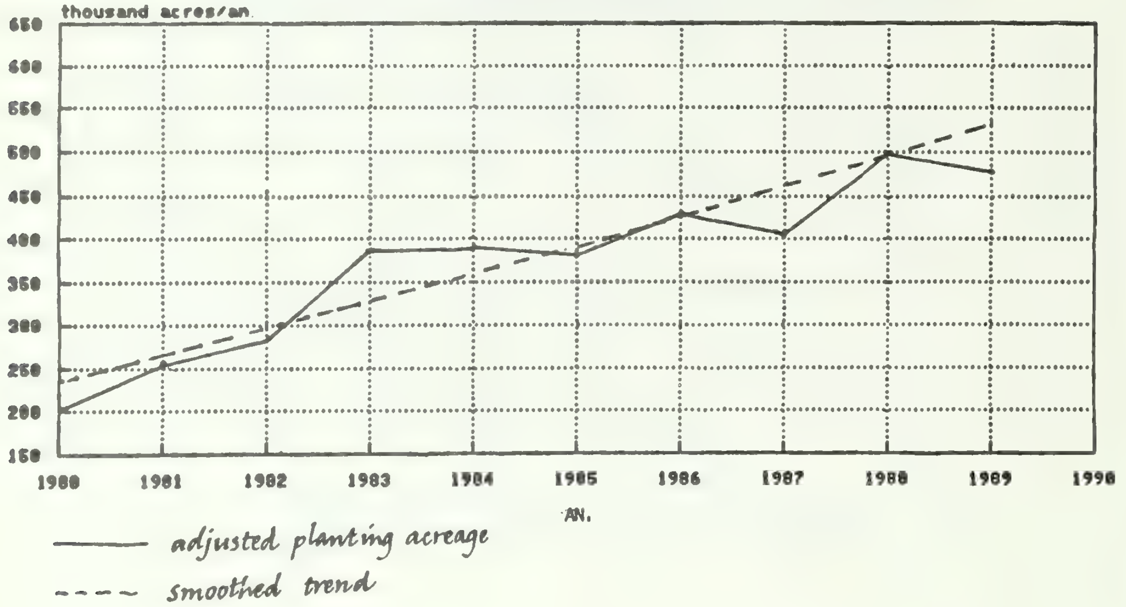
FIGURE 9. PLANTATION AGE DISTRIBUTION

Midsouth States (1978)



Based on planting records

FIGURE 10. Projected Commercial Thinning Acres
Midsouth Plantations



us to estimates for Mississippi and Louisiana. The Mississippi survey was chosen because it is the most recent one completed among the important Gulf Coast states. We are currently updating the inventory of Louisiana so it too seemed a logical choice. It must be noted that yields identified on existing plantations may be poor predictors of future yields on well-managed forest industry lands. Nonetheless, the data we have collected reflects a real work situation in which many plantation acres are not managed at the intensity of some forest industry lands.

Our inventories are based on the careful measurement of not only dbh, but of upper stem diameters on thousands of trees 5.0 inches and larger at breast height. Computation of merchantable volume is on data for an individual tree using routines developed by L. Grosenbaugh. Volumes of individual trees are expanded to a per-acre basis and recorded in cubic feet per acre. Further calculations of cords per acre are based on utilization studies.

Distribution of site classes (Figure 11) might give an idea of the potential number of acres producing better returns than those reported in Tables 1 - 4. Notice that the better sites are producing at least 85 cu. ft./acre. Based on our cubic foot to standard cord conversion factors, this is a little more than 1 cord per acre per year.

Thinning yields of pine only in Mississippi and Louisiana are low compared to those found in the Southeastern region. Two of many possible reasons for this condition are cited. First, muc of the data comes from Soil Bank era planting. O average these acres reflect a lower intensity of management--typical of many NIPF acres. Second, in some areas hardwood competition forms a significant portion of the basal area and volume. (The volumes reported are strictly for pine).

Tables 1 - 4 summarize average stocking and volumes in plantations in Mississippi. Our table represent volumes on medium site lands. Total area refers to the estimate of the acres in a given age class. Yields refer to probable cords per acre produced as a result of thinning an average acre to 60 square feet of basal area and conversion of cubic foot volume to standard cords Volumes reported are exclusively pine. Table 1 portrays volumes and stocking for the Northern Unite (2) of Mississippi. Plantations are primarily Loblolly on pine type sites. Table 2 shows similar parameters for Central Mississippi (Unit 3). The probable thinning yields are highest for this unit, still they are lower than e projections given for Atlantic South antations of medium site. Table 3 (Unit 4 utheast Mississippi) is characterized by lower r acre volumes and basal areas at age 15 for tes which are primarily slash pine type. Totals r the state are not much different than the dividual units. The potential yields reported re are for average conditions, but they suggest at the 15 year age class (a class dictated by ventory data collection routines) is still a ttle young to expect substantial thinning

The young loblolly plantations in Louisiana (ages - 10 and 11 - 20) were compared to expected elds which are predicted in the Forest Service blication Yields of unthinned Loblolly pine antations on cutover sites in the west Gulf gion (SO-148, Feduccia, et al.). Based on the mber of trees surviving, site index and age nce planting there was remarkable agreement, on e average, between the predicted yields and totals served inventory. The numbers of cords of pine ailable through thinnings generally follows the ttern established in Mississippi data.

We feel that average volumes will be nsiderably greater when the increases in forest dustry managed lands begin to appear in the atistics. In addition if we remember that antation forestry was much better developed in e Atlantic South during the Soil Bank era it is nd's production levels is present in the ssissippi-Louisiana data than in comparable lantic data. There is also a good deal of lume in hardwood on the plantations found in ssissippi. If this volume is directly utilized converted to pine through proper site occupancy d maintenance, it increases the net volumes ailable from the site significantly. Stands ich will reach thinning age during the 80's iginated more recently than the ones analyzed d the impact of improved forest management ould be realized during the 80's.

To put potential volumes in perspective, nsider the pulp production for the seven-state ea (Figure 12). There were a total of 25 llion standard cords reported in Southern lpwood Production, 1977. During the past 20 ars roundwood production has increased gnificantly from 6 million to 12 million andard cords per year. Most of the increase curred between 1965 and 1970. The most recent creases in overall pulp production have come om better utilization of wood residues. Wood sidues, which accounted for 5 - 15 percent of e pulp production during the 1960's, now ntribute 35 percent of the total. Further ansions in pulping capacity may be possible through gains in utilization of residues. However, a major opportunity for increased production will be available from thinnings, especially toward the end of the coming decade. Potential thinning volumes in the Midsouth at the end of the period will approach 1.25 million cords even at conservative levels used for predicition in this paper. This represents nearly 15 percent of the current annual softwood roundwood production. If average per acre volumes increase significantly due to the impact of better management expected in the region during the 80's, the figure could be closer to 5 million cords or 50 percent of the total.

In summary, review Figure 10. Regardless of the interval between planting and commercial thinning, be it 15 or 20 years, there is an imminent expansion of the acres suitable for thinning in the Midsouth. This expansion willtake place during a period of anticipated economic uncertainty. This could signal a shift in emphasis onto activities that are economically efficient, which could have a serious impact on the potential production of many acres needing to be thinned during the decade. Finally, I'd like to comment on our current, midcycle update of Louisiana Forest Resources. We have obtained high altitude photographs of the pine regions of Louisiana and are currently in the process of constructing an aerial photo key to the condition of recently planted forest industry lands On the ground examination of chosen sites has been completed. We expect to have preliminary results indicating the condition and extent of young Louisiana plantations early in 1981.

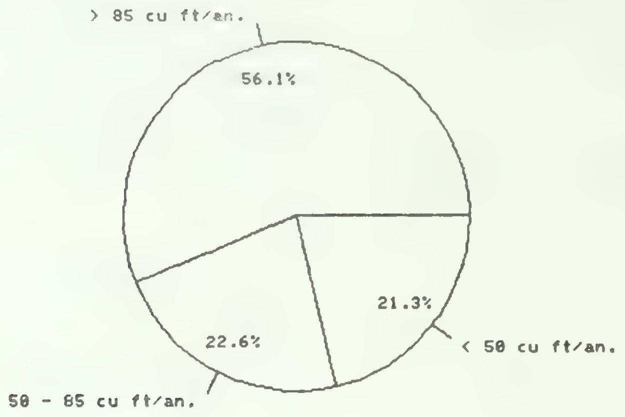
LITERATURE CITED

Bertelson, D. F., 1978 Southern Pulpwood Production, 1978. USDA For. Serv. Resource Bull. SO-74, 21 pp.

Feduccia, D. P., T. R. Dell, W. F. Mann, T. E. Campbell and B. H. Polmer. 19 . Yields of Unthinned loblolly pine plantations on cutover sites in the West Gulf region. USDA For. Serv. Res. Pap. SO-148, 88 pp.

1977. Forest Statistics of the U. S., 1977. USDA For. Serv. 133 pp.

FIGURE 11. DISTRIBUTION BY SITE CLASS
Plantations in Mississippi



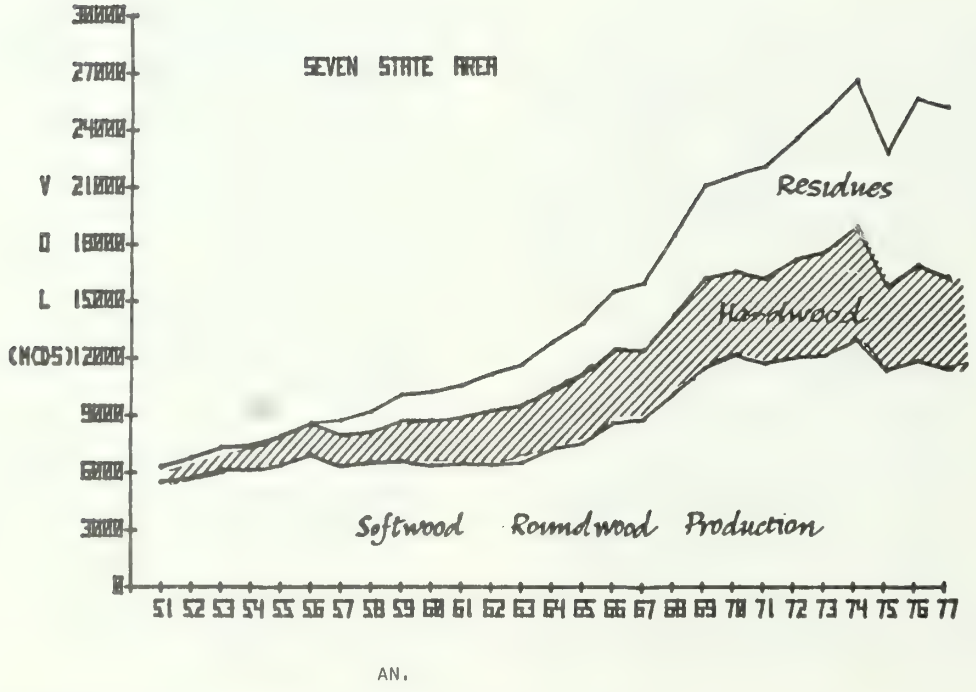


FIGURE 12. Midsouth Pulp Production 1951-1977

Table 1.--Average stocking and volume per acre and acreages
Mississippi Unit 2. (Primarily Loblolly)

Stand age	Trees 5.0 in. dbh and larger			Total Area [1]	
	Basal Area	net volume	standard	thousand	
	(sq. ft.)	(cu. ft.)	cords	acres	
5	30	665	8.9	98	
15	68	685	9.1	242	thinned to 60 ft.^{2} yield = 1 cord
25	85	1146	15.3	132	
35	66	1154	15.4	81	
Mixed	[2]				

[1] Forest survey estimate of total plantation acres in an age class.

[2] Too few plots to make any estimate.

Table 2.--Average stocking and volume per acre and acreages
Mississippi Unit 3. (Primarily Loblolly)

Stand age	Trees 5.0 in. dbh and larger			Total Area	
	Basal Area	net volume	standard	thousand	
	(sq. ft.)	(cu. ft.)	cords	acres	
5	11	100	1.3	179	
15	78	1060	14.2	46	thinned to 60 ft.^{2} yield = 3.2 cords
25	105	1920	25.6	35	
35	60	1100	14.7	29	
Mixed	60	1112	14.8	17	

Table 3.--Average stocking and volume per acre and acreages Mississippi Unit 4. (Primarily slash)

Stand age	Trees 5.0 in. dbh and larger Basal Area (sq. ft.)	net volume (cu. ft.)	standard cords	Total Area thousand acres	
5	9	60	.8	317	less than 60 ft.^{2}
15	55	615	8.2	238	no yield
25	80	1065	14.2	68	
35	45	1425	25.0	11 2/	
Mixed	26	265	3.5	23 2/	

2/ Very rough estimates.

Table 4.-- Average stocking and volume per acre and acreages State totals for Mississippi (includes unit 1 & 5)

Stand age	Trees 5.0 in. dbh and larger Basal area (sq. ft.)	net volume (cu. ft.)	standard cords	Total Area thousand acres	
5	13	170	2.2	622	thinned to 60 ft.^{2}
15	66	730	9.7	547	yield = 0.8 cord
25	85	1230	16.4	236	
35	68	1300	17.3	126	
Mixed	50	670	8.9	52	

SYCAMORE PLANTATION GROWTH: 10-YEAR RESULTS OF SPACING TRIALS[1]

Bryce E. Schlaegel[2]

Abstract.--Results of a 10-year spacing trial for sycamores on a good site in the Mississippi Delta are presented. Total cubic-foot production is correlated to initial number of stems, with the 5x10- and 10x10-foot spacing having twice the volume and weight of the widest spacing of 20x20 feet. Projected ages of peak MAI for the 5x10-, 10x10-, 10x20-, and 20x20-foot spacings are 12, 18, 22, and 30 years, respectively. The 10x10 spacing appears to give the most options for production of either pulpwood or sawlogs.

The American sycamore (*Platanus occidentalis* grows relatively fast throughout its life. amore appears most frequently and attains its rgest size on alluvial soils. Only cottonwood *pulus deltoides* Bartr. ex Marsh.), and in some es, black willow (*Salix nigra* Marsh.) grow ster there (Merz 1958). Because of its rapid wth and relative freedom from serious insect disease pests, sycamore is widely planted oughout the South. But before establishing a est plantation, an initial spacing must be ermined.

Early sycamore growth is influenced by tial seedling density. Belanger and Pepper 78) show that total height is decreased by cking that is either extremely high or low. al height was greatest at intermediate stock- levels of 1,000 to 5,000 trees per hectare 0 to 2,000 trees per acre). Moderate compe- n among trees was necessary to obtain maximum ght growth.

Close initial spacing offers high yields in ly years. Stem yields of 4-year-old seedlings ged from 14.5 oven-dry tons per acre at a 1x4- t spacing to 5.9 tons at a 4x6 spacing ucier et al. 1972).

Wide spacing distributes growth on fewer stems. The result is larger trees, but the age of maximum mean annual increment is increased. At 11 years of age, mean annual increment was still increasing for Georgia Piedmont sycamore planted at an 8x8-foot spacing (Belanger and Saucier 1975).

This paper presents 10-year results of a sycamore spacing trial with spacings of 5x10, 10x10, 10x20, and 20x20 feet. The spacings are compared for survival, wood density, and present height, basal area, volume, and weight. The age at which stand cubic-foot mean annual increment (MAI) peaks is projected for each spacing.

METHODS

Installation and Measurement

The study area is located in the Mississippi River batture at Huntington Point near Greenville, Miss. The soil is Commerce silt loam, a good sycamore site averaging 108 feet in site index for natural sycamore stands.

A randomized complete block design of four blocks and four spacings was planted in the spring of 1970 with 1/0 seedlings. The spacings and respective numbers of trees per acre were 5x10 feet (871), 10x10 (436), 10x20 (218), and 20x20 (109). Competition from herbaceous and woody vegetation was reduced by mechanical disking several times a year for the first 2 years.

Each of the 16 plots consists of a 13x13-row sample plot, the interior 7x7-measurement rows and 3 buffer rows. Annual dbh measures are taken on 49 measurement trees; total heights are measured on the center two rows, or about 15 trees.

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[1] Paper presented at Southern Silvi- tural Research Conference, Atlanta, Georgia, ember 6-7, 1980.

[2] Mensurationist, Southern Hardwoods Labo- ory, which is maintained at Stoneville, sissippi, by the Southern Forest Experiment tion, Forest Service--USDA, in cooperation h the Mississippi Agricultural and Forestry eriment Station and the Southern Hardwood est Research Group.

Deriving Volume and Weight Equations

Volume and weight equations exist for plantation-grown sycamore in the Georgia Piedmont (Belanger 1973). However, these equations were developed from trees of a single 8x8-foot spacing using form factor equations. Using Belanger's equations in this spacing study to calculate tree volumes and weights overestimates tree volumes in the widely-spaced plots and underestimates tree volumes in the narrowly-spaced plots. The net result is to mask the differences in tree form that exist between spacings. To overcome this problem, separate volume and weight equations were developed for each spacing.

During the summer of 1979, five trees per plot were randomly selected and felled from the middle border row of each plot, for a total of 20 sample trees per spacing. Stump heights were about 0.2 feet. Sample disks were removed from the base of the stem and at intervals of H/20, each disk coming from the same relative position on the stem; an additional disk was removed at dbh.

A stem analysis was done on each disk by measuring annual rings on the average disk radius. Bark thickness on the average radius was measured to the nearest 0.04 inch. Tree volume for each annual sheath was calculated by summing bolt volumes calculated by Newton's formula (Husch et al. 1972).

Outside bark radii for prior years were estimated by regressing current radius outside bark (ROB) separately for each spacing as a linear function of radius inside bark (RIB) so that ROB = a + b (RIB). A random sample of three disks from each tree were used to represent all ages and sizes of disks. The following tabulation gives estimates of a and b for the preceding model for predicting outside bark radius in inches from a known inside bark radius:

Spacing	a	b	R^2	$S_{y.x}$
5x10	0.027	1.018	0.99966	0.012
10x10	0.026	1.021	0.99973	0.001
10x20	0.032	1.021	0.99937	0.001
20x20	0.026	1.030	0.99964	0.001

After the stem analysis, the odd-numbered disks were analyzed for moisture content and specific gravity. All odd-numbered disks for each tree were consolidated into a single sample for that tree. All bark was removed, the disks were collectively weighed green, volumes obtained by water immersion, and then ovendried in a forced fan oven at 105°C for 48 hours. Moisture content and specific gravity were obtained for each tree. Since no way was available for estimating specific gravity for individual ages, the assumption was made that tree wood density of each spacing has remained constant over time and estimated stem dry weight at the ith age (DW_i) as the product of its volume from the stem analysis (V_i) times its present average specific gravity (SG) times 62.43;

i.e. $DW_i = V_i \times SG \times 62.43$.

Volumes and weights obtained from stem analysis were treated as independent observations and fit by nonlinear least squares techniques to the model

$$W_i = b_0 D_i^{b_1} H_i^{b_2} \qquad (1)$$

where

D_i = the dbh of the ith tree.

H_i = total tree height of the ith tree.

W_i = stem cubic-foot volume or dry weight in pounds of the ith tree.

The parameter estimates and accuracy statistics for model 1 are presented in table 1. All data fit the model with a fit index of at least 0.975.

Deriving the Height Equations

The volume equations require both diameter and total height measures. However, only dbh was measured on all trees each year. Therefore, total height was estimated for each tree in order to calculate tree volume and weight.

Plotting total tree height over dbh for each spacing for all ages indicated that initial spacing greatly influences average total tree height. Low densities had significantly less height growth for the first 5 years. This agrees with the results of Belanger and Pepper (1978). Therefore, a separate height prediction model was fit for each spacing as a function of tree dbh and age:

$$H_i = b_0 + b_1 X_i + b_2 X_i^2 \qquad (2)$$

where

$X_i = A_i \mathrm{Ln}(D_i)$; the natural logarithm of the dbh of the ith tree times its age

H_i = total height in feet, and

the b_i are coefficients estimated from the data (table 2).

Table 1.--Parameter[1] estimates and accuracy statistics for estimating sycamore bole wood volume and weight[2]

Spacing	n	b_0	b_1	b_2	Fit index[3]	Standard error of estimate	Coefficient of variation[4]
Feet						*Feet*	*Percent*
				Cubic-foot volume			
5x10	198	0.00219	1.82368	1.10810	0.979	0.17	12.0
10x10	195	0.00270	1.88955	1.02193	0.993	0.15	6.9
10x20	189	0.00210	1.88815	1.08123	0.990	0.20	8.2
20x20	195	0.00252	1.66346	1.14185	0.979	0.46	13.2
				Dry weight - pounds			
5x10	198	0.05842	1.97868	1.04351	0.975	4.98	13.2
10x10	195	0.06783	1.87341	1.04794	0.991	4.53	7.7
10x20	189	0.05508	1.94481	1.06576	0.986	6.82	10.1
20x20	195	0.08832	1.87976	0.96516	0.979	13.07	13.3

[1] $\hat{Y} = b_0 D^{b_1} H^{b_2}$

[2] Volumes and weights of trees from a 0.2 foot stump to the tree tip.

[3] Fit index = $1 - [\Sigma(Y-\hat{Y})^2/\Sigma(Y-\bar{Y})^2]$.

[4] Coefficient of variation = 100 (standard error of estimate/$\bar{Y}$).

Table 2.--Coefficients through age 10 for estimating sycamore total tree height (feet) for a given spacing[1]

Spacing	Coefficient b_0	Coefficient b_1	Coefficient b_2	R^2	Standard error of estimate	Coefficient of variation[2]
Feet					*Feet*	*Percent*
5x10	15.33	2.93319	-0.04012	0.857	3.56	8.6
10x10	12.89	2.81507	-0.02270	0.950	2.68	6.1
10x20	14.28	2.06441	-0.00218	0.900	3.27	7.8
20x20	13.80	1.54306	0.01468	0.932	3.24	8.0

[1] $H = b_0 + b_1 [A\mathrm{Ln}(D)] + b_2 [A\mathrm{Ln}(D)]^2$; A = tree age, D = dbh.

[2] Coefficient of variation = 100 (standard error of estimate/$\bar{Y}$).

RESULTS

After 10 years the 5x10-foot spacing averages 77% survival while the other three spacings average 93% (table 3). This high mortality in the narrow spacing is due to competition, since at the end of two growing seasons no differences in survival existed due to spacing. Average stand height of all trees is about 5 feet lower for the 5x10 spacing, a reversal from age 5 when the two narrow spacings averaged 4 feet taller than the two widest spacings.

Average dbh is related directly to spacing; tree dbh increases with an increase in spacing.

Total basal areas per acre range from 49 sq. ft. for the 20x20-foot spacing to 84 sq. ft. for the 5x10-foot spacing. Similarly, bole wood volumes range from 1,057 to 2,011 cu. ft. per acre and bole dry weights range from 29,660 to 53,509 pounds per acre. The 10x10 spacing has the same volume as the 5x10 and a higher dry weight per acre due to higher wood specific gravity. The 20x20 spacing has only about one-half the volume as the 5x10. But 94% of the volume is on trees 8 inches dbh and larger, while the two narrow spacings average 2% and 15% on large diameter trees (table 4).

Specific gravity is directly correlated with growth rate, with the faster-growing trees exhibiting the highest specific gravity at 0.452 while specific gravity for the slower-growing trees averages 0.422. These figures are considerably lower than either the 0.54 (Panshin et al. 1964) or 0.49 (U.S. Forest Products Laboratory 1974), which have been listed for the species. But similar results due to spacing were noted by Saucier et al. (1972).

Although mean annual increment (MAI) has not yet peaked for any of the spacings in this study (fig. 1), it can still be determined for each of the spacings by separately considering the components of stand volume

Volume (V) of an even-aged stand can be determined if three factors are known: 1 - its basal area (B), 2 - its average total height (H). and 3 - the average form factor (F). Thus,

$$V = FBH \qquad (3$$

and cubic-foot volume mean annual increment is

$$MAI = V/A = (FBH)/A \qquad (4$$

or,

$$MAI = (FB)\ H/A, \qquad (5$$

where A is the stand age in years and V, F, B, and H are previously defined.

Equations were derived for each spacing to estimate B, F, and H/A. Substituting these into (5) and solving for each year show that MAI will peak for the 5x10, 10x10, 10x20, and 20x20-foot spacing at ages 12, 18, 22, and 30, respectively, Table 3.--Average 10-year results for a sycamore spacing trial

Item	Spacing 5x10	 10x10	 10x20	 20x20
Survival - *percent*	77	90	96	94
Dbh - *inches*	4.8	6.1	7.4	9.4
Total height - *predicted feet*	50	55	54	55
Basal area per acre - *sq. ft.*	84	80	61	49
Bole wood volume per acre - *cu. ft.*	2,011	2,003	1,435	1,057
Bole dry weight per acre - *pounds*	53,509	54,256	39,739	29,660
Wood specific gravity	0.422	0.429	0.439	0.452
Bole form factor	0.478	0.454	0.435	0.391

Table 4.--Distribution by dbh class of bole wood cubic-foot volume of a 10-year-old sycamore spacing trial

Dbh class	Spacing 5x10	 10x10	 10x20	 20x20
		Volume - *cubic feet*		
1	1			
2	8			
3	101	17	1	
4	525	70	10	1
5	690	278	58	3
6	470	690	153	26
7	175	647	343	38
8	41	252	519	122
9		49	322	270
10			29	251
11				217
12				129
Total	2011	2003	1435	1057
% ≥8" dbh	2	15	61	94

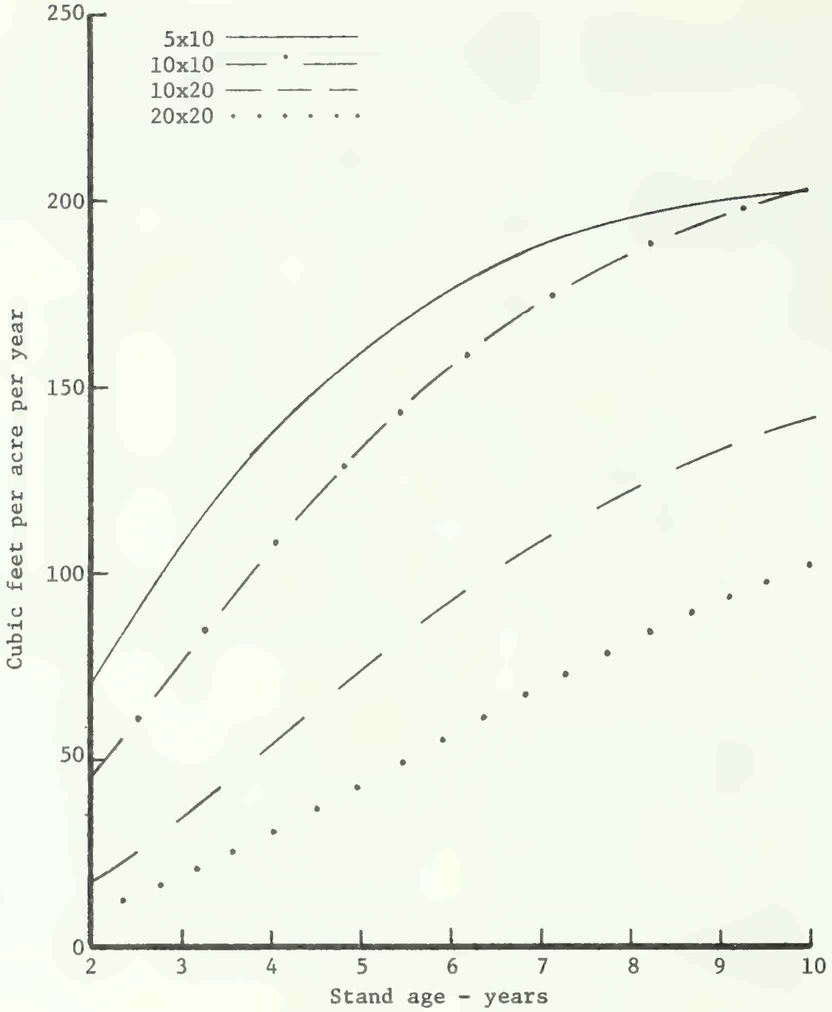

Figure 1.--Cubic-foot volume mean annual increment for a sycamore spacing trial.

with peak MAI's of 204, 219, 167, and 144 cu. ft. per acre per year.

DISCUSSION

Results after 10 years show that tree size and stand volume and weight are directly affected by initial spacing. The closer spacings result in relatively higher stand volume at age 10 than wide spacings, but average tree size is smaller. The 20x20 spacing has only half the volume of the close spacings, but it is placed on small sawlog-sized trees.

Initial spacing will depend upon the product objectives. If fiber is the sole objective, then a close initial spacing with a complete clearcut and replanting when MAI peaks should be the management strategy.

A wide initial spacing will produce small sawlogs by age 10. However, the site is underutilized until the crowns close. And sawlog quality is low due to lack of natural pruning until after crown closure.

The most favorable spacing in this study appears to be the 10x10. It has volume or weig equal to or better than the 5x10 with half the initial density. It can be clearcut for fiber age 18 when MAI peaks. Or it can be row-thinne after natural pruning to the height of one sawlog, at about age 9 or 10. This would give an arly investment return and leave clean-boled rees for future sawlog production.

LITERATURE CITED

elanger, Roger P.
1973. Volume and weight tables for plantation-grown sycamore. U.S. Dep. Agric. For. Serv. Res. Pap. SE-107, 8 p. Southeast. For. Exp. Stn., Asheville, N.C.

elanger, Roger P., and William D. Pepper.
1978. Seedling density influences the early growth of planted sycamore. For. Sci. 24(4): 493-496.

elanger, Roger P., and Joseph R. Saucier.
1975. Intensive culture of hardwoods in the South. Iowa State J. Res. 49(3): 339-344.

Husch, Bertram, Charles I. Miller, and Thomas W. Beers.
1972. Forest mensuration. New York: The Ronald Press Co., 410 p. + vii.

Merz, Robert W.
1958. Silvical characteristics of American sycamore. U.S. Dep. Agric. For. Serv. Central States For. Exp. Stn. Misc. Release 26, 20 p.

Panshin, A. J., C. DeZeeuw, and H. P. Brown.
1964. Textbook of wood technology. Vol. I. McGraw-Hill Book Co., New York. 643 p. + xiii.

Saucier, J. R., A. Clark III, and R. G. McAlpine.
1972. Above ground biomass yields of short-rotation sycamore. Wood Sci. 5(1):1-6.

U.S. Forest Products Laboratory.
1974. Wood handbook: wood as an engineering material. U.S. Dep. Agric., Agric. Handb. 72, rev.

TAPER FUNCTIONS FOR UNTHINNED LONGLEAF PINE PLANTATIONS ON CUTOVER WEST GULF SITES[1]

V. C. Baldwin, Jr. and B. H. Polmer[2]

Abstract.--Longleaf pine stem taper was modeled using unthinned plantation data from 10 Texas and Louisiana stands. Sample trees were 10 to 44 years old with dbh from 1 to 21 inches. Inside- and outside-bark taper functions are presented and discussed.

INTRODUCTION

Standing tree volume estimation by appropriate integration of a taper curve is one of the most accurate and flexible techniques available. Taper functions also facilitate estimation of other parameters such as stem surface area. The method is particularly valuable when multiproduct yields are desired.

Taper functions for loblolly and slash pine are used in some of the most recent yield prediction systems (Bennett et al. 1978; Dell et al. 1979; Feduccia et al. 1979) and a number of taper models for these species have been published (e.g., Liu and Keister 1978; Max and Burkhart 1976; Matney and Sullivan 1980). To date, however, a taper model for planted longleaf pine has not been published although one has been fitted for natural longleaf stems and publication is pending.[3] As part of a study to develop green- and dry-weight equations for unthinned longleaf pine plantations, inside- and outside-bark taper functions were fitted and are described in this paper. The models were developed by Bennett et al. (1978) and later applied by Dell (1979) and Dell et al. (1979). Equation development and rationale for the models are covered in those publications.

DATA

Sample trees came from long term growth and yield study plots established in 10 unthinned longleaf pine plantations located on cutover sites in central Louisiana and east Texas. Plantation ages ranged from 10 to 44 years and site index (base age 25) ranged from 41 to 76.

Trees were selected to represent a wide dbh range in three varying height classes per diameter class and three crown ratio classes per height class. Crown ratio (in percent) is defined as 100 (length of full live crown)/(total height of the tree). Distribution of the sample trees by dbh, crown ratio, height and age is presented in table 1. Sample trees were free from forking, excessive sweep, and any effects of disease or mechanical damage which would tend to make them atypical. Measurements were taken during the summer of 1979.

Total height, dbh, and height to the base of the live crown were measured for each tree before felling. After felling all measurements were repeated for verification. Following removal of all branches from the bole, diameter inside- and outside-bark and height above groundline were measured at dbh and at each 1-inch taper step from the stump to the tip. For both inside- and outside-bark measurements, the average of two caliper readings to the nearest 0.1 inch were recorded at each measurement point.

THE MODELS

Since the basic model assumptions, derivations and applications are given in detail in Bennett et al. (1978) and Dell et al. (1979), only the models used and the information needed for application with planted longleaf pine are presented.

Define:

h = height above ground (feet),

h_s = average stump height (feet),

D = diameter outside bark at breast height, (inches),

H = total tree height (feet),

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

[2] Baldwin is Research Mensurationist at Pineville, LA. Polmer is Statistician at New Orleans, LA for the Southern Forest Experiment Station, USDA Forest Service.

[3] R. M. Farrar, personal communication, 1980.

$CR(i)$ = the ith crown ratio class where

$i = 1$ when, $CR < 36$ percent,

$i = 2$ when, $36 \text{ percent} \le CR \le 50$ percent,

$i = 3$ when, $CR > 50$ percent,

(h) = a general expression for the predicted diameter inside bark (inches) as a function of height (h) above the ground,

(h) = as immediately above for diameter outside bark (inches).

Different expressions for $d_{ib}(h)$ or $d_{ob}(h)$ used for $h \le 4.5$ feet and $h \ge 4.5$ feet but the er models are constrained so the two segments e together at breast height.

The models are:

Outside-bark taper model,

$$(h) = \begin{cases} D(h/4.5)^{\eta_{ob}}, & h_s \le h \le 4.5 \quad (1a) \\ D(H-h)/(H-4.5) \\ + \beta_{1_{ob}} (H-h)(h-4.5)/H^2 \\ + \beta_{2_{ob}} D(H-h)(h-4.5)/H^2 \\ + \beta_{3_{ob}} D^2 (H-h)(h-4.5)/H^2 \\ + \beta_{4_{ob}} (H-h)(h-4.5)(2H-h-4.5)/H^3, & 4.5 \le h \le H \quad (1b) \end{cases}$$

II. Inside-bark taper model,

$$\hat{d}_{ib}(h) = \begin{cases} (\gamma_1 + \gamma_2 D)(h/4.5)^{\eta_{ib}} & h_s \le h \le 4.5 \quad (2a) \\ (\gamma_1 + \gamma_2 D(H-h)/(H-4.5) \\ + \beta_{1_{ib}} (H-h)(h-4.5)/H^2 \\ + \beta_{2_{ib}} \cdot (\gamma_1 + \gamma_2 D)(H-h)(h-4.5)/H^2 \\ + \beta_{3_{ib}} (\gamma_1 + \gamma_2 D)^2 (H-h)(h-4.5)/H^2 \\ + \beta_{4_{ib}} (H-h)(h-4.5)(2H-h-4.5)/H3, & 4.5 \le h \le H \quad (2b) \end{cases}$$

These inside- and outside-bark models were fitted to our data using least squares estimation procedures. Separate sets of coefficients were independently estimated for each of the three broad crown ratio classes defined. The model coefficients and associated fit statistics are presented in table 2.

Taper functions are commonly used to obtain stem volume of standing trees. Cubic-foot volume inside- or outside-bark for a stem section between heights h_1 and h_u ($h_1 < h_u$) is estimated by revolving the appropriate taper curve, $d_{(\ )}(h)$ between h_1 and h_u for a given CR(i) around the h-axis. The mathematical expression for the volume of this solid of revolution is

$$Vol_{(\ )} = \int_{h_1}^{h_u} \pi[d_{(\ )}(h)]^2/4(144)\ dh. \qquad (3)$$

The specific inside- and outside-bark volume predicting equations resulting from evaluation of the above integral are lengthy and therefore are not presented here. The prediction equations are given in Bennett _et_ _al._ (1978) and utilization of their equations with our coefficients is straightforward. Also, the USLYCOWG computer program (Dell _et_ _al._ 1979; Feduccia _et_ _al._ 1979) contains the complete volume predicting system in subroutines which only need slight alteration and input of our coefficients for use with longleaf pine.[4]

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[4] The USLYCOWG FORTRAN computer program is available from the Southern Forest Experiment Station, Statistical Methods for Research and Application, T-10210, 701 Loyola Avenue, New Orleans, LA 70113.

DISCUSSION AND CONCLUSIONS

Data were not available for direct validation of our models. However, a number of internal and external checks were made.

All the taper equations were evaluated by summarizing trends in deviations between predicted and observed values for the observations upon which they were based, and graphs were developed to ensure that predictions were reasonable. No unusual or misleading predictions were discovered. The statistics given in table 2 do reflect the generally good fit obtained in the modeling process.

A number of taper-graph sets, similar to those in figure 1, were produced for different height, diameter and crown ratio combinations so we could visualize model performance over a range of conditions. The graphs clearly illustrate, for example, the thicker bark and greater taper in the high, as compared to the low, crown ratio trees.

The volume equations derived from our taper models were also used to generate total and merchantable cubic-foot volumes, within each crown ratio class, for a number of total height and dbh combinations (table 3). These volumes were compared with volumes predicted in the same manner by other longleaf pine volume equations. Models used were (1) Schmitt and Bower (1970), (2) U. S. Forest Service (1929) and (3) Farrar.[5]

The Schmitt and Bower equations were the only plantation pine volume predictors available, but they were developed to estimate small tree (< 8 inches dbh inside bark) cubic-foot volumes in young plantations. The FS publication offers volumes in tabular form only for fully stocked natural stands of longleaf pine throughout the South. Farrar's data came from naturally established thinned and unthinned stands in the east Gulf Region. Comparisons were made subject to data restrictions imposed both by our equations and the other equations. This requirement was relaxed somewhat for the Schmitt and Bower comparisons because of the differences in tree heights between the two data sets. Table 3 gives the dbh-height combinations used for these comparisons. The volumes predicted from the other equations were considered to be those "observed" in the statistics we generated.

For each situation considered, the correlation of "observed" and predicted total inside-bark volumes was computed. Also computed was the mean percent deviation, which is the average of the 100 (predicted-"observed")/"observed" values. In each case the correlation coefficient was positive and at least r = .99. These statistics offered assurances that the equations were at least predicting in a general manner like unto the others.

However, the mean percent deviations revealed the most interesting points and confirmed some expecte results:

Reference Model	Mean Percent Deviation CR < 36	 36 ≤ CR ≤ 50	 CR >
1 Schmitt and Bower	4.46	2.26	-17
2 US Forest Service	-0.78	-1.41	- 8
3 Farrar	-0.94	-1.65	- 8

Overall, these statistics indicate the model predictions were biologically as well as mathemat cally meaningful. For example, the noticeably lo mean percent deviations in the high crown ratio c in each case reflect the magnitude of total volum overprediction for these trees. This result migh expected when any volume equations are used which not account for tree taper differences. The resu confirm that in most cases a higher crown ratio i longleaf pine trees implies comparatively lower t stem volumes. The higher crown ratio generally results from a more open stand structure during t development and thus more taper in the upper ste of the trees.

Also, the last six slightly negative mean p deviations suggest our model may underpredict vo if used in natural longleaf pine stands. This f ing, although not conclusive, is reasonable assu total tree volumes in longleaf pine plantations be less, on average, than volumes of natural lon trees of the same dbh and height because of the greater upper stem taper expected in plantation which are grown under relatively low density, re ly spaced conditions.

There are exceptions, of course. Dell (197 pointed out that for certain situations volumes greater with higher crown ratios in the low- to portions of plantation loblolly and slash, and natural longleaf pine stems. In our data this phenomenon was also evident in trees less than 8 inches dbh in the stem portion from about 5 to 1 feet above groundline.

A comparison with the Schmitt and Bower (19 young plantation equation (model 1) also indica the importance of considering age, initial plan spacing and present stand structure before sele a particular volume equation. Our functions ov predicted volumes using the CR(1) and CR(2) mod but noticeably underpredicted with the CR(3) mo The trees used to build Model 1 had a wide init spacing (10' x 10') and most were expected to h crown ratios exceeding 50 percent. However, th CR(3) model apparently did a poor job of predic the volumes of those trees relative to, say, th CR(2) model. Although the crown ratio distribu of the Model 1 plantation trees isn't known, it known that they were younger and shorter, on av than those used in our model (age 7 years and range of 5-33 feet). This compares with a mean 26 years, and height range of 12-70 feet, respe for trees in the dbh range indicated in table 3. However, most of our low dbh sample trees were older, suppressed or intermediate trees and not indicative of the typical trees found in young, vigorously growing plantations. Also, the size of our sample in these smaller diameter classes was only one-fourth the size of theirs. And there is always the problem of greater estimate variability when using predictors that are close to the endpoints of the model's database. Hence, in spite of the advantages of our taper models, the Schmitt and Bower (1970) equation is a better volume model to use in young, widely spaced longleaf pine plantations.

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[5] Farrar, R. M. Cubic-foot volume, surface area, and merchantable height functions for longleaf pine trees. Manuscript in preparation.

When using these taper models for any desired application, the crown ratio classes are broad enough so standing trees can easily be assigned a crown ratio class visually, if height to the base of the live crown was not measured, and the appropriate equation utilized. Proper crown ratio class assignments can also be made fairly accurately based on plantation age and density. Lacking any of this information, the model for the middle crown ratio class should be used.

LITERATURE CITED

Bennett, F. A., F. T. Lloyd, B. F. Swindel, and E. W. Whitehorne.
1978. Yields of veneer and associated products from unthinned, old-field plantations of slash pine in the North Florida and South Georgia flatwoods. USDA Forest Service Research Paper SE-176, 80 p.

Dell, T. R.
1979. Potential of using crown ratio in predicting product yield. pp. 843-851 In: Proceedings, Forest Resource Inventories Workshop, Vol. II, Edited by W. E. Frayer, Colorado State University, Fort Collins, Colorado. July 23-26, 1979.

Dell, T. R., D. P. Feduccia, T. E. Campbell, W. F. Mann, Jr., and B. H. Polmer.
1979. Yields of unthinned slash pine plantations on cutover sites in the West Gulf Region. USDA Forest Service Research Paper SO-147, 84 p.

Feduccia, D. P., T. R. Dell, W. F. Mann, Jr., T. E. Campbell, and B. H. Polmer.
1979. Yields of unthinned loblolly pine plantations on cutover sites in the West Gulf Region. USDA Forest Service Research Paper SO-148, 88 p.

Liu, C. J., and T. D. Keister.
1978. Southern pine stem form defined through principal component analysis. Can. J. Forest Res. 8:188-197.

Matney, T. G., and A. D. Sullivan.
1980. Inside- and outside-bark taper equations for old-field plantation loblolly pine trees in the central Gulf Coastal Plain. Mississippi Agricultural and Forestry Experiment Station Technical Bulletin 101, 28 p.

Max, T. A., and H. E. Burkhart.
1976. Segmented polynomial regression applied to taper equations. Forest Sci. 22:283-289.

Schmitt, D., and D. Bower.
1970. Volume tables for young loblolly, slash, and longleaf pines in plantations in south Mississippi. USDA Forest Service Research Note SO-102, 5 p.

U. S. Department of Agriculture Forest Service.
1976. Volume, yield, and stand tables for second-growth southern pines. U. S. Dep. Agric. Forest Service, Misc. Publ. 50, 202 p. [Rev. 1929 ed.].

Table 1.--Distribution of the sample trees by diameter, live crown ratio, height and age, and the recommended maximum range of taper curve application (inside heavy lines)

D.B.H. class	Age Mean	Age Range	Total Height Mean	Total Height Range	Number of trees	Distribution by height class*: Short	Medium	Tall	Distribution by crown ratio class†: CR < 36	36 ≤ CR ≤ 50	CR > 50
1	26	25-27	12	12-14	3	0	1	2	1	2	0
2	23	10-40	19	15-23	8	3	2	3	2	3	3
3	27	23-40	34	20-46	8	2	2	4	2	2	4
4	24	22-25	44	33-54	6	1	3	2	2	2	2
5	24	22-27	47	36-58	6	2	3	1	2	1	3
6	28	22-40	51	33-66	6	2	3	1	3	0	3
7	26	22-40	60	44-70	7	1	4	2	1	3	3
8	30	22-40	70	58-79	6	0	3	3	2	3	1
9	28	22-40	69	57-83	8	3	1	4	1	6	1
10	33	23-40	77	73-85	8	1	2	5	3	5	0
11	35	22-44	76	62-87	8	1	4	3	2	3	3
12	30	22-40	79	65-86	5	1	1	3	0	2	3
13	33	23-40	79	71-87	6	1	2	3	1	3	2
14	39	23-44	81	74-90	6	0	2	4	0	3	3
15	37	23-44	82	76-85	5	0	1	4	0	4	1
16	42	40-44	77	69-88	5	2	1	2	0	3	2
17	44	40-44	78	70-90	5	1	3	1	0	1	4
18	43	40-44	83	79-86	3	0	1	2	0	0	3
19	43	40-44	75	72-78	3	1	2	0	0	0	3
20	--	--	--	--	-	-	-	-	-	-	-
21	44	44	83	83	1	0	0	1	0	0	1
Totals	33	10-44	62	12-90	113	22	41	50	22	46	45

*Short, medium and large tree height classes increase relative to increases in diameter.
†CR = Live crown ratio in percent.

Table 2.--Equation coefficients and statistics of fit for the taper models

	$CR^* \leq 36$			$36 \leq CR \leq 50$			$CR \geq 50$		
Coefficient	Estimate	$R^{2\dagger}$	$SEE^{\#}$	Estimate	R^2	SEE	Estimate	R^2	SEE
$\hat{\beta}_{1_{ob}}$	17.005064	.9345	.3021	12.714490	.9924	.4049	7.064397	.8724	.4937
$\hat{\beta}_{2_{ob}}$	1.215630			2.024789			1.082622		
$\hat{\beta}_{3_{ob}}$	- 0.008585			- 0.072514			-0.029041		
$\hat{\beta}_{4_{ob}}$	-14.123470			-12.484350			-5.707780		
$\hat{\eta}_{ob}$	- 0.086751	.8552	.0772	- 0.091896	.9320	.0468	-0.102462	.9327	.0510
$\hat{\beta}_{1_{ib}}$	14.091790	.9443	.2779	6.309718	.9223	.4083	-1.018126	.8814	.5022
$\hat{\beta}_{2_{ib}}$	1.187514			2.217892			1.178190		
$\hat{\beta}_{3_{ib}}$	- 0.003004			- 0.088708			-0.032456		
$\hat{\beta}_{4_{ib}}$	-11.655900			- 7.667510			0.285117		
$\hat{\eta}_{ib}$	- 0.084656	.7552	.1043	- 0.082441	.8986	.0522	-0.093852	.8103	.0838
$\hat{\gamma}_1$	- 0.393140	.9938	.2375	- 0.302410	.9967	.2434	-0.595800	.9938	.4270
$\hat{\gamma}_2$	0.937690			0.917050			0.915140		

*CR = live crown ratio in percent

†R^2 = coefficient of determination

#SEE = standard error of the estimate

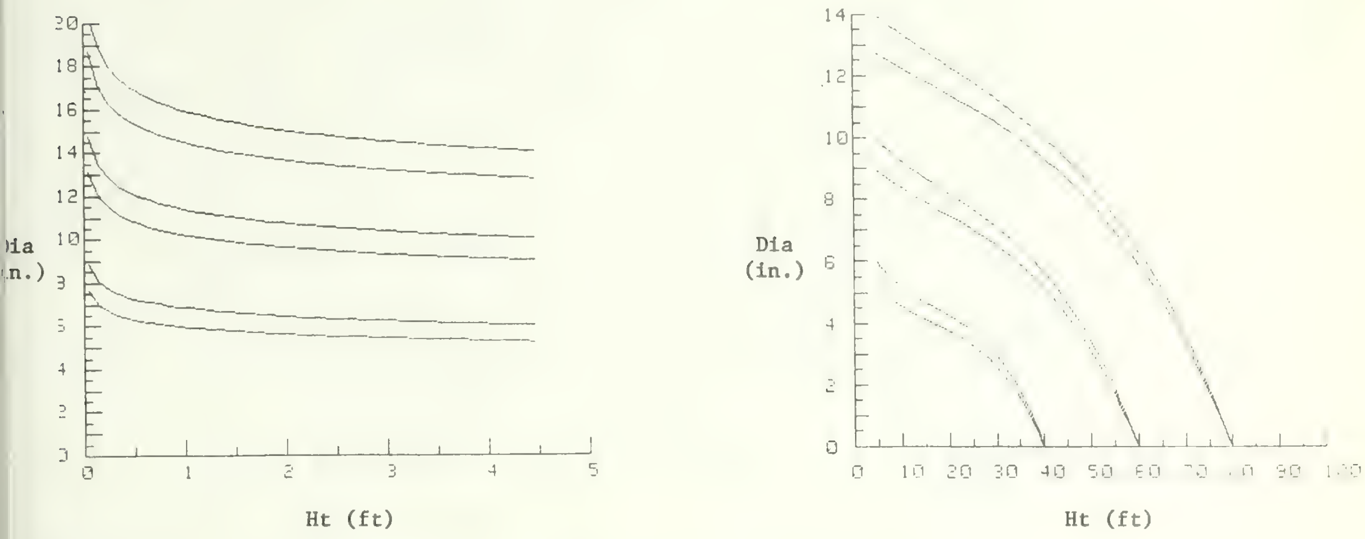
Table 3.--Diameter at breast height-total height combinations used in taper function versus alternative functions volume prediction comparisons*

Diameter (in.)	Total height (feet) 10	15	20	25	30	40	50	60	70	80	90
2	S	S	S								
3		S	S	S							
4			S	S	S,F,U	F,U	F,U				
5				S	S						
6				S	S,F,U	F,U	F,U	F,U			
7					S						
8						F	F,U	F,U	F,U	F,U	
10							F	F,U	F,U	F,U	U
12								F	F,U	F,U	F,U
14								F	F,U	F,U	F,U
16									F,U	F,U	F,U
18									F	F,U	F,U

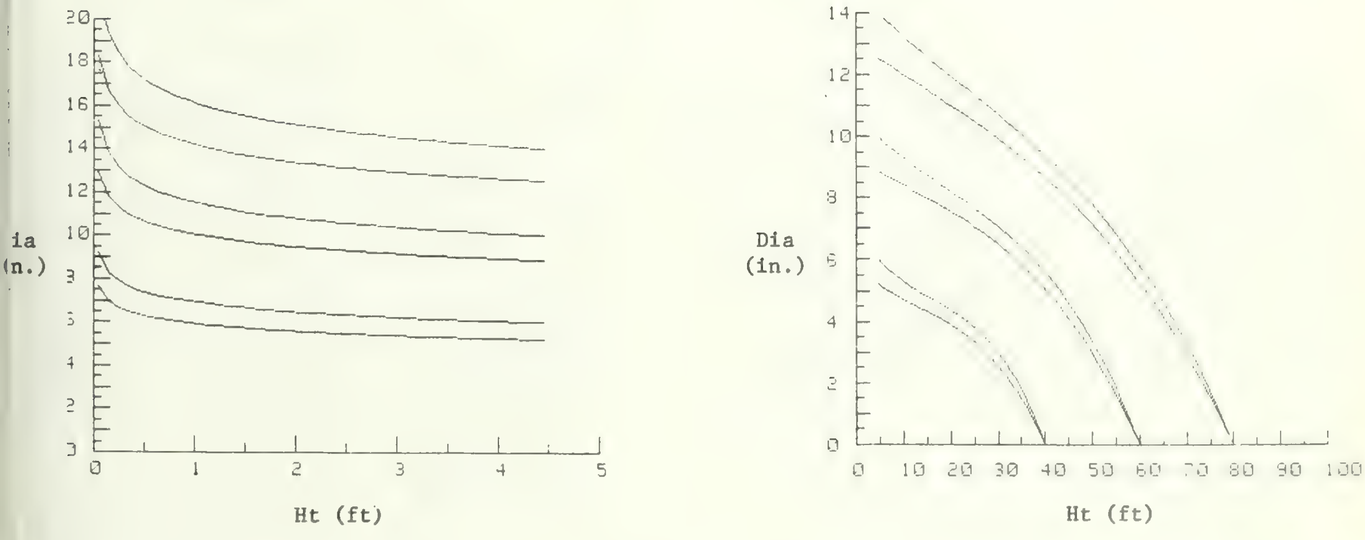
*S, F or U indicates that a Schmitt and Bower (1970), Farrar, or USDA Forest Service (1929) equation, respectively, predicted total volume, for the given height-diameter combination, was compared with a taper equation volume predicted for the same height and diameter.

Figure 1.--Examples of inside- and outside-bark taper for three trees of typical dimensions for three live crown ratio classes

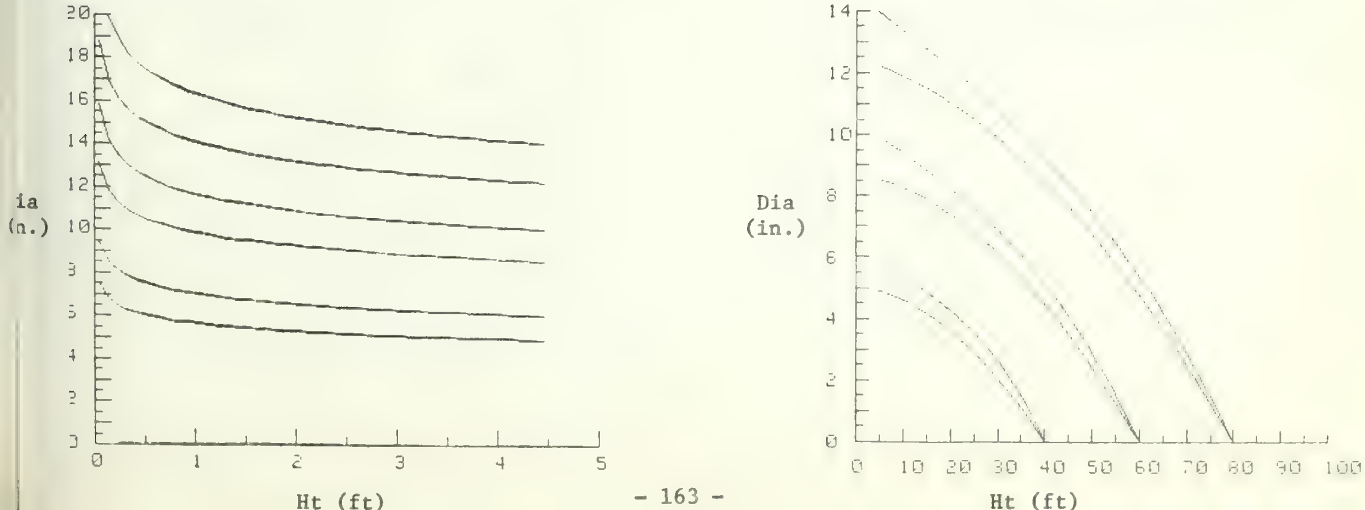
CR < 36



$36 \leq CR \leq 50$



CR > 50



EVALUATING A DIAMETER-LIMIT CUT IN SOUTHERN APPALACHIAN HARDWOODS THROUGH STEM ANALYSIS[1]

Donald E. Beck[2]

Abstract.--Stem analysis of all trees on sample plots was used to evaluate a diameter-limit cut made 27 years earlier. Most of the present stand developed from the 71 saplings and poles per acre with 26 square feet of basal area that remained after harvest. These trees ranged from 35 to 137 years old and were in suppressed and intermediate crown positions prior to release. Growth response was surprisingly good.

THE SITUATION

Numerous broad-scale studies of silvicultural systems and harvest cutting methods were installed on experimental forests 25 or more years ago. Many such areas are intact and can furnish much information on long-term stand development. In one case on Bent Creek Experimental Forest near Asheville, North Carolina, records showed that a 6.5-acre stand had been cut to a diameter limit 27 years previously in 1952-53. Cruise records by 2-inch diameter class for trees 5 inches and larger show that before the cut the stand contained 119 trees with 81 square feet of basal area and 7,834 board feet of sawtimber per acre (tables 1 and 2). By basal area, the stand was 49 percent oak (Quercus spp.), 34 percent yellow-poplar (Liriodendron tulipifera), 9 percent red maple (Acer rubrum), and 8 percent miscellaneous species. The stand is situated on the lower one-third of an east-facing slope. Site quality is excellent with site index for yellow-poplar of 100 feet or more at 50 years.

Table 1.--Number of trees per acre, by diameter class [1]

Species	Diameter class									Total
	6	8	10	12	14	16	18	20	22+	
	inches									
	1952									
Yellow-poplar	13.5	8.5	5.7	7.2	5.7	2.8	.6	.3	.5	44.8
Oak [2]	8.6	8.7	6.6	4.0	6.8	4.4	1.8	1.4	3.2	45.5
Red maple	6.9	5.4	1.5	1.1	.8	.6	.3	.1	--	16.7
Locust	--	1.2	.8	.5	1.1	.1	--	.1	--	3.8
Misc. [3]	6.8	.6	.8	--	.3	--	--	--	--	8.5
Total	35.8	24.4	15.4	12.8	14.7	7.9	2.7	1.9	3.7	119.3
	1954									
Yellow-poplar	11.4	7.1	6.6	1.2	--	--	--	--	--	26.3
Oak	8.3	7.0	4.9	3.5	1.4	--	--	.1	--	25.2
Red maple	5.8	3.5	.9	.5	.1	--	--	--	--	10.8
Locust	--	1.2	.8	.5	--	--	--	--	--	2.5
Misc.	5.9	--	--	--	.1	--	--	--	--	6.0
Total	31.4	18.8	13.2	5.7	1.6	--	--	.1	--	70.8
	1979									
Yellow-poplar	14.0	16.6	13.8	7.7	8.2	8.2	5.2	2.9	1.4	78.0
Oak	1.0	2.6	3.8	3.3	3.7	4.4	2.8	1.0	1.0	23.6
Red maple	3.7	5.2	5.8	2.6	2.1	1.7	.8	.5	.1	22.5
Locust	1.7	2.3	.5	.5	.5	.1	.1	--	--	5.7
Misc.	4.4	3.2	.8	1.1	.6	.1	.3	--	--	10.5
Total	24.8	29.9	24.7	15.2	15.1	14.5	9.2	4.4	2.5	140.3

[1] Based on 100-percent cruise by 2-inch diameter classes, i.e., 6-inch class includes trees 5 to 6.9 inches, etc.
[2] Predominately white oak with some black and northern red.
[3] Includes hickory, sweetbirch, sourwood, and others.

Table 2.--Stand conditions, per acre

Stand	No. of trees	Basal area	Volume
		---ft^2---	--fbm--
Original stand 1952	119	81	7,834
Residual stand 1954	71	26	288
Stand after 27 years 1979	140	110	8,023
Growth/acre/year		3.1	297

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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Harvesting rules called for removal of all yllow-poplar over 10 inches in diameter at east height (d.b.h.) and other species over 12 iches. The harvest cut removed 51 trees with 1546 board feet per acre. In 1954 the residual sand had 71 trees per acre--mostly less than 12 iches d.b.h. (table 1). Basal area averaged 26 suare feet per acre and only 288 board feet of swtimber volume remained. Of the residual stems cer 6 inches d.b.h., 37 percent were yellow-pplar, 36 percent oaks, 15 percent red maple, and te remaining 12 percent were miscellaneous spe-ces such as hickory (Carya spp.), dogwood (Cornus forida), sourwood (Oxydendrum arboreum), etc.

A 100-percent cruise of the stand in 1979-- years after the diameter-limit cut--showed a sand with 148 trees per acre with 110 square fet of basal area and 8,023 board feet of saw-tmber (tables 1 and 2). Of those trees large eough to grade, 24 percent were grade 1, 39 per-cnt grade 2, 32 percent grade 3, and only 5 prcent cull. Since the diameter-limit cut, the sand had grown at the rate of 3.1 square feet of bsal area and 297 board feet per acre per year--very respectable showing! The stand gave all apearances of a vigorous, even-aged stand of mxed species composition.

THE PROBLEM

From the available records of the initial sand, cutting records, and residual stand in 154, we could only speculate about the origin of te high-quality sawtimber trees that were pre-snt in 1979. Did they come from the trees 6 to inches d.b.h. that were left? Were trees in tat category intermediate and suppressed trees would seem to be the case? Or were they yunger, vigorous, developing trees that existed openings? Or was the present stand derived fom trees regenerating after the diameter-limit t in 1952? Could we predict similar response fr other stands cut in a similar manner?

In order to answer these questions, stem aalysis was used to reconstruct the age and size istribution of the current stand at the time of te diameter-limit cut and to determine response the cut.

METHODS

Plot Establishment

Four 1/5-acre circular plots were established a stratified random manner to account for ap-rent site variation as indicated by topographic sition and land surface configuration. Within ech plot, all trees in the main canopy were tal-led by species, d.b.h., total height, and tree ade. Each tree location was mapped by distance fom plot center and azimuth. All understory trees er 4.5 feet tall were tallied by species and dia-ter.

Stem Analysis

After felling, each tree on the 1/5-acre plot was sectioned at breast height and intervals up the bole to the tip. Length of interval above breast height was 4 feet to the 16-foot level, and 8 feet thereafter. Ring counts and height above-ground were recorded for each section point. A disk removed at breast height was taken to the lab for ring counts and measurement under magnification. Growth measurements were made on six radii to account for eccentricities in growth.

Information generated for each tree from the stem analysis consisted of status at time of diameter-limit cut in terms of: age, d.b.h., total height, height growth for the 5 years before and after release, diameter growth for the 5 years before and after release, height and diameter growth for the 27 years after release.

RESULTS AND DISCUSSION

The four plots were similar in species composition, size, and age distribution. Therefore, plot data were combined for analysis and discussion.

Age Structure

Age (table 3) for the dominant stand (dominant, codominant, and intermediate crown classes) in 1979 ranged from 26 to 164 years. However, the ages were not randomly distributed over that range, but fell in some rather obvious groupings. Of 81 trees, 24 (30 percent) were less than 27 years old and originated as a result of the 1952 timber harvest. Yellow-poplar dominated this category. These trees were almost certainly of stump-sprout origin as attested to by height growth pattern, evidence of stumps, and other studies in the area (Beck 1977).

Table 3.--Age structure of dominant stand, 1979 [1]

Age class	Yellow-poplar	Locust	Red maple	Oak	Hickory	All
< 27	21	3	--	--	--	24
31 - 40						--
41 - 50						--
51 - 60						--
61 - 70	10		5			15
71 - 80	9		4	2	1	16
81 - 90	5		6	--	1	12
91 - 100				1	2	3
101 - 110				2	1	3
111 - 120				3	1	4
121 - 130					1	1
131 - 140						--
141 - 150				1		1
151 - 160					1	1
161 - 170				1		1
Total	45	3	15	10	8	81

[1] Number of trees in intermediate, codominant and dominant crown classes on four 1/5-acre plots.

A second grouping of 43 trees (53 percent) consisted primarily of yellow-poplar and red maple 60 to 90 years old. The origin of these trees can be associated with a period around 1900 when the land was acquired by the Vanderbilt Estate, farming ceased, and fire protection begun.

The remaining 14 trees (17 percent) included oak and hickory and originated over a 90-year period beginning around 1810 when the land was first settled and cleared for agriculture. Historical records for the Bent Creek Experimental Forest suggest the land was subjected to grazing, burning, and periodic high grading throughout that period (Nesbitt 1941).

Size Structure

Height and diameter of the dominant stand in 1979 and as it existed in 1952 at the time of release is summarized by species in table 4. Despite the rather wide range in ages of the different species, the height of trees in 1979 in the dominant stand was similar, with species averages ranging from 85 to 92 feet. In terms of diameter, the oaks had a sizable advantage over all species except yellow-poplar stems already in place in 1952. A few of the yellow-poplar that originated as stump sprouts in 1952 developed into codominant crown positions. But for the most part, these younger trees were somewhat smaller than trees beginning as residuals, and they occupied an intermediate crown class position.

Table 4.--Size distribution of dominant stand, by species

Species	1979				1952			
	Height		D.b.h.		Height		D.b.h.	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
	- - ft - -		- inches -		- - ft - -		- inches -	
Oak	[illegible]	[illegible]	16.7	13.5-22.2	[illegible]	[illegible]	9.9	4.4-12.3
Hickory	[illegible]	[illegible]	11.	7.9-19.4	[illegible]	[illegible]	[illegible]	[illegible]
Red maple	[illegible]	[illegible]	13.0	7.6-22.0	[illegible]	23-85	6.0	1.7-13.1
Yellow-poplar:								
Residuals	[illegible]	[illegible]	[illegible]	7.5-22.0	57	16-92	[illegible]	[illegible]
New	[illegible]	[illegible]	9.4	5.8-15.1	--	--	--	--
All	[illegible]	[illegible]	12.9	5.8-22.0	--	--	--	--

The average size of oak trees in 1952 was larger than that of other species. Over 80 percent of the oaks were larger than 7 inches d.b.h. and over 50 feet tall when released. Most would appear to have occupied intermediate crown classes before release. Hickory had a wide range of sizes but were mostly less than 5 inches d.b.h. and less than 50 feet tall. Red maple and yellow-poplar showed the widest range in size of responding trees. But they too were concentrated in the smaller size classes. Some trees that were 11 to 12 inches d.b.h. and over 80 feet tall probably were strong intermediates or possibly codominants before the diameter-limit cut. Others that were 2 to 3 inches d.b.h. and less than 25 feet tall at 30 to 40 years of age could only have been severely suppressed trees. If grown unrestricted, yellow-poplar of the same age could easily obtain a height of 80 to 90 feet and 13 to 15 inches d.b.h. Red maple would be only slightly smaller. Over 40 percent of the responding yellow-poplar were less than 5 inches d.b.h. and 50 feet tall with a range in age from 35 to 50 years. A good share of the responding yellow-poplar and red maple were probably suppressed trees.

Growth Response

In order to examine growth response, I compared height and diameter growth for the 5-year periods before and after release (tables 5 and 6). The diameter growth is for wood only and does not include bark.

Table 5.--Five-year diameter growth before and after diameter-limit cut

Species	Before cut		After cut		Percent increase
	Mean	Range	Mean	Range	
	- - - - - - - - - inches	- - - - - - - - -			
Oak	.52	.18- .99	1.56	.86-2.45	200
Hickory	.29	.13- .65	.95	.16-1.24	228
Red maple	.44	.13-1.22	1.53	.55-2.47	248
Yellow-poplar	.57	.24-1.51	1.84	.28-3.00	223

Table 6.--Five-year height growth before and after diameter-limit cut

Species	Before cut		After cut		Increase
	Mean	Range	Mean	Range	
	- - - - - - - - - feet	- - - - - - - - -			
Oak	3.0	[illegible] - 4	3.2	2 - 5	7
Hickory	2.4	1 - 4	4.0	2 - 6	67
Red maple	3.3	1 - 8	6.7	2 - 19	103
Yellow-poplar	3.3	1 - 7	6.3	2 - 19	91

Rate of diameter growth prior to release was extremely slow for all species, reaffirming the poor competitive position of the trees. Hickory, the slowest grower, averaged nearly 35 rings per inch. Yellow-poplar, the fastest, averaged nearl 18 rings per inch prior to release.

Diameter growth response was immediate and dramatic for all species, ranging from a 200-percent increase for the oaks to a 248-percent increase for red maple. After release, diameter growth rates ranged from 0.95 inches in 5 years for hickory to 1.84 inches for yellow-poplar. These rates are comparable to those for good-vig trees of similar species and size.

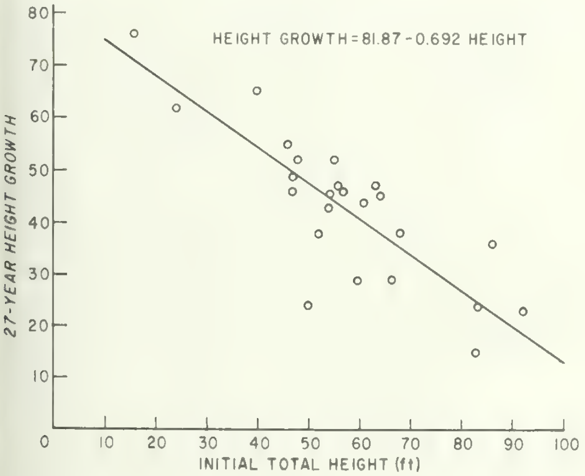
Height growth response in the first 5 years after release was not as great as diameter respo and was more variable among species. The oaks increased in height only slightly. The small response is not surprising because the trees had already obtained a considerable part of the heig potential for the site at time of release. Red maple and yellow-poplar nearly doubled their rat of height growth on the average. Many of the shorter trees (20- to 30-foot class) of these species grew three to four times faster after release.

The total amount of height growth in the 7 years since release varied from an average of 4 feet for the oaks to 45 feet for yellow-poplar table 7). Yellow-poplar presents a particularly nteresting case. The amount of growth was nversely proportional to the height at time of elease (fig. 1). The rate of height growth fter release was close to that expected of trees f a similar height but much younger age and hich have always been in a dominant or codominant osition (Beck 1962). Age of tree, per se, had ittle effect on the rate of growth. Figure 2 hows representative height growth patterns for ome individual trees that were a) suppressed esiduals at time of diameter-limit cut, and b) tump sprouts originating at time of the cut. ote the similarity of growth patterns between esiduals after release and stump sprouts.

Table 7.--Total growth for 27-year period after release by diameter-limit cut

Species	Height		D.b.h.	
	Mean	Range	Mean	Range
	- - - feet - - -		- - inches - -	
Oak	24	17-37	7.6	5.6-10.5
Hickory	33	[illegible]	5.1	2.9- 7.9
Red maple	38	12-56	[illegible]	[illegible]
Yellow-poplar 1/	45	23-76	[illegible]	3.8-15.8

1/ Includes only those trees established prior to the cut.



igure 1.--Height growth of yellow-poplar in relation to initial height.

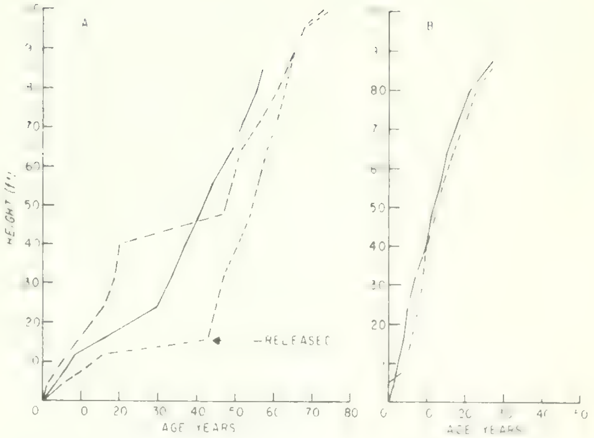


Figure 2.--Height growth of selected yellow poplar (a) residuals, (b) stump sprouts.

SUMMARY AND CONCLUSIONS

A diameter-limit cut which removed yellow-poplar trees over 10 inches d.b.h. and other species larger than 12 inches resulted in a mixed stand of good quality and high vigor 27 years later. Through complete stem analysis of all trees on four 1/5-acre plots, I was able to reconstruct the status of surviving trees at the time of the harvest cut.

A portion of the 1979 stand (30 percent) was made up of yellow-poplar that originated as stump sprouts after the diameter-limit cut. Some of these trees attained codominant crown status, but most were in an intermediate position. The remainder of the stand (70 percent) resulted from trees present at time of the cut. Trees from wide ranges of age, d.b.h., and height responded to release. The oaks and hickory that responded averaged nearly 80 years of age; some were over 150 years old. Yellow-poplar and red maple were mostly 50 to 60 years old at time of release. Response occurred in trees from less than 2 to greater than 12 inches and from 16 to 92 feet in height.

A few of the larger poles that responded may have been codominant crown classes before release. However, size, age, and rates of growth suggest that most trees were suppressed and intermediate crown classes. Regardless of age and size, response to release was immediate for all species involved. Growth rates after release were comparable to what might be expected of trees of equal size but of much younger ages. The quality of sawtimber trees is good. Rapid height growth of responding trees and new stump sprouts apparently formed a closed stand quickly, promoted natural pruning, and prevented development of wolf trees.

The results of this study parallel the findings of Smith and Lamson (1977) for a similar diameter-limit cut in West Virginia. In their study a stand dominated by oak species was cut to a 9-inch diameter. The residual stand of 110 trees per acre in the 5- to 9-inch diameter classes developed into a well-stocked stand with 7,425 board feet of sawtimber per acre in 25 years. They speculated that most of the sawtimber developed from the pole-size material left after the logging. It should be noted that in both cases a good number of poles of desirable species were present in the residual stand. Also both sites were of good quality for tree growth.

We should not assume that all upland hardwood stands will respond as favorably as this one. Nor should we recommend diameter-limit cuts as a standard operating procedure. In fact, there are undoubtedly instances where repeated diameter-limit harvests have caused deterioration of both quality and quantity of growth. However, the response here suggests that it may not always be necessary to follow current recommendations to cut or kill all residual stems over 1 or 2 inches d.b.h. during clearcut harvesting. There may be other situations where saplings and poles capable of response are present in sufficient numbers after commercial harvests to provide acceptable growth and quality. We need further information on different sites with varied stocking conditions and species combinations to define those conditions and to establish guidelines.

LITERATURE CITED

Beck, D. E.
1962. Yellow-poplar site index curves. USDA For. Serv. Res. Notes 180, 2 p. Southeast. For. Exp. Stn., Asheville, N.C.

Beck, D. E.
1977. Growth and development of thinned versus unthinned yellow-poplar sprout clumps. USDA For. Serv. Res. Pap. SE-173, 11 p. Southeast. For. Exp. Stn., Asheville, N.C.

Nesbitt, William A.
1941. History of early settlement and land use on the Bent Creek Experimental Forest. Files at Southeast. For. Exp. Stn., Asheville, N.C.

Smith, H. Clay, and N. I. Lamson.
1977. Stand development 25 years after a 9.0-inch diameter-limit first cutting in Appalachian hardwoods. USDA For. Serv. Res. Pap. NE-379, 4 p. Northeast. For. Exp. Stn., Broomall, Pa.

GROWTH AND YIELD PREDICTIONS FOR LOBLOLLY PINE--THE COOPERATIVE RESEARCH PROGRAM AT VIRGINIA TECH[1/]

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Abstract.--The Loblolly Pine Growth and Yield Research Cooperative was initiated at Virginia Tech in 1979 to develop the methodology necessary to accurately predict growth and yield in intensively managed loblolly pine plantations. This paper summarizes research completed since inception of the Cooperative and reports progress on current studies and proposed future research.

INTRODUCTION

The last several years have witnessed table advances in growth and yield prediction thodology. Many of these new techniques have een successfully applied to forest stands in e Southeast. However, adequate predictions r the wide range of management and utilization tions that managers now wish to evaluate are t available. Management options such as inning, site preparation, fertilization and e planting of genetically superior stock re-ire accurate growth and yield response data r evaluation. In addition, changing utiliza-on standards have magnified the need for added exibility in growth and yield modeling. exible prediction techniques adaptable to a riety of product mixes are essential.

In light of the urgency for more reliable ediction techniques and the scope of the task, e Loblolly Pine Growth and Yield Research operative was initiated at Virginia Tech in 79. The Cooperative is currently comprised of ten private industrial firms and three public agencies.[3/]

Funds supplied by the cooperators support one full time research associate and several graduate research assistants. In addition to financial support, cooperators contribute data for growth and yield modeling and validation and assist in defining pertinent research emphases.

Dealing strictly with loblolly pine, the Cooperative's objectives are two-fold:

1. The major long-term goal involves developing the methodology necessary to accurately assess growth and yield in intensively managed loblolly pine plantations. This necessitates a continuum of data collection, analysis and interpretation. As research reveals knowledge gaps, additional studies can be designed with appropriate data collection efforts.

2. The interim short-term goals consist of utilizing available data to supply cooperators with suitable solutions until long-term objectives can be achieved. This often includes searching various sources, both within and without the Cooperative, for pertinent data.

[1/] Paper presented at Southern Silvicul-ral Research Conference, Atlanta, Georgia, vember 6-7, 1980.

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[3/] Industrial members are Bowater Incorporated, Champion International, Chesapeake Corporation of Virginia, Continental Forest Industries, Crown Zellerbach, Federal Paper Board Company, International Paper Company, Potlatch Corporation, Westvaco Corporation and Weyerhaeuser Company. Public agencies include the U.S. Forest Service and the North Carolina and Virginia Divisions of of Forestry.

The purpose of this paper is to summarize recent research completed since inception of the Cooperative and report progress on current studies and proposed future research.

PREDICTING CONTENTS OF INDIVIDUAL TREES

Over the last several years, various models have been developed for predicting merchantable volume of individual trees. The models fall into one of two categories: taper equations, which when integrated between limits of height and diameter will yield volume of any particular portion of the bole, and volume ratio models which predict some merchantable volume as a ratio of total volume.

Under the Cooperative, development and testing of these types of models are continuing. Cao et al. (1980) examined several different taper equations and volume ratio equations. Each model was evaluated in terms of cubic foot volume and diameter prediction and each was ranked according to the following three criteria:

1. Bias - the mean of the differences between the actual and predicted values.

2. Mean absolute differences - the mean of the absolute differences.

3. Standard deviation of the differences.

Their results show that the choice of an appropriate model depends on the objective. For describing tree taper, a segmented polynomial (Max and Burkhart 1976) was deemed best. For predicting merchantable volume to a specified top diameter or height, the nonlinear volume ratio models (Burkhart 1977 and Cao et al. 1980) were judged superior. A model which does well at predicting both diameters and volumes is a new taper equation of the form:

$$(d^2KH/V-2Z)=b_1(3Z^2-2Z)+b_2(Z-a_1)^2I_1+b_3(Z-a_2)^2I_2$$

where

d= diameter at height h
H= total tree height
Z= $(H-h)/H$
V= total tree volume
K= 0.005454 if d is in inches and V in cubic feet
a_1, a_2 = join points
I_i= 1 if $Z \geq a_i$; $i=1,2$,
= 0 if $Z < a_i$.

The precision with which tree taper can be predicted based only on dbh and total height is, however, limited due to other influencing factors. Cultural practices such as thinning and pruning affect tree taper with thinning generally tending to increase taper and pruning fostering more cylindrical stems (Larson 1963, Kozlowski 1971). These practices directly affect crown size. As a result, the Cooperative recently supported work which examined relationships between crown ratio and tree taper.[4]

This research effort was a two-pronged study, first examining the possibility of including crown ratio to improve the precision of diameter prediction from taper equations and secondly, studying the effect of different silvicultural treatments on bole form. Data for the first study came from unthinned old-field loblolly pine plantations in North Carolina, Virginia, Maryland and Delaware. Data used in the analysis of treatment on bole form came from the North Louisiana Hill Farm Experiment Station in Homer, Louisiana. These data consist of plots treated with thinning, pruning, thinning and pruning, and control.

Conclusions resulting from this study were:

1. Crown ratio is related to tree taper, but, for many practical situations, the relationship is not strong enough to warrant the extra effort and expense required to include it as an independent variable in a taper equation.

2. In untreated stands, stand variables such as age, site index and number of trees per acre have relatively little impact on tree taper. Therefore, equations using dbh and total height as independent variables are sufficient to predict tree taper over a wide range of stand characteristics.

3. When measured several years after treatment, little difference in bole form between thinned, pruned, or thinned and pruned loblolly pine was found. Using separate taper equations for trees subjected to these treatments does not appear to be justifiable under many practical circumstances.

POLYMORPHIC SITE INDEX CURVES

Devan (1979) derived base-age invariant polymorphic site index curves for planted and natural stands of loblolly pine.[5] The objective of the study was to develop an improved site index model for loblolly pine. The new model was then compared to other existing models for accuracy, precision and logical characteristics.

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[4] Burton, Sally S. 1980. The influence of crown ratio on taper predictions of loblolly pine (Pinus taeda L.). Unpublished Masters Thesi Va. Polytech. Inst. & State Univ., Blacksburg, VA

[5] Devan, James S. 1979. Base-age invariant polymorphic site index curves for loblolly pine. Unpublished Masters Thesis, Va. Polytech. Inst. & State Univ., Blacksburg, VA.

Data for the study were obtained from 356 lots of natural and planted stands of loblolly ine in Virginia, North Carolina, Maryland and elaware. Statistical tests showed separate quations were needed for the following groups:

1. natural stands
2. plantations on cutover sites
3. plantations on old-field piedmont sites
4. plantations on old-field coastal plain ites.

In order to fit the data, a segmented model as developed which joins two separate models - ne for younger ages and one for older ages. The ollowing model, modified from Lenhart (1968)[6], was pplied:

$$\frac{dy}{dx} = b_0+b_1x+b_2x^2+b_6y \qquad X \leq L$$

$$= b_3+b_4x+b_5x^2+b_6y \qquad X > L$$

here

L = 1/join point age

$\frac{dy}{dx}$ = instantaneous rate of height growth

y = ln (height)

x = 1/Age

Independent data were available for evaluating the curves for old-field plantations. These ndependent data consisted of 27 trees from peranent plots on old-field piedmont sites in irginia. Measurements were recorded three times sually at five-year intervals beginning at age 2, 13 or 14. Using these data, the join point odel was compared to anamorphic curves in urkhart *et al.* (1972) and polymorphic curves in urkhart (1973)[7]. Results showed the new join oint model underestimated the site index by an verage of less than two feet over roughly a tenear span. The anamorphic curves (Burkhart *et al.* 972) were next best and underestimated the site ndex by an average of 8.8 feet. The polymorphic urves of Burkhart (1973) underestimated site ndex by an average of 9.7 feet.

No independent data were available for evaluating the natural stand or cutover site plantation curves. However, the natural stand curves did appear to exhibit logical trends but the cutover site plantation curves, which were based on an extremely small sample size from young plantations, appeared to "flatten" at too early an age. In general, the polymorphic curves for old-field plantations and natural stands are somewhat "steeper" than most published site index curves for comparable conditions.

STAND GROWTH AND YIELD

Assembly of Existing Data

The Loblolly Pine Growth and Yield Research Cooperative memberships' landholdings stretch across the natural range of loblolly pine. The diversity of sites and climatic conditions is enormous, making the task of developing relevant growth and yield predictions complex. In order to meet the immediate needs of cooperators for growth and yield prediction models for stand characteristics that are applicable across a wide variety of sites, data representative of these sites were assembled from various locations in the Southeast. Table 1 summarizes these data.

Table 1. Data sets currently being analyzed by the Loblolly Pine Growth and Yield Research Cooperative.

Cultural Treatment	Type	Physiographic Region	Geographic Location by State
Unthinned	old-field	coastal plain-piedmont	VA, MD, DE, NC
Unthinned	old-field	coastal plain	MS, AL
Unthinned	old-field	coastal plain	TX, AR, LA
Unthinned	old-field	piedmont	GA
Thinned	old-field	coastal plain-piedmont	VA
Thinned	old-field	coastal plain-piedmont	NC, SC, GA, VA, MD

The unthinned old-field data are representative of much of the natural range of loblolly pine. These data, which are primarily from several earlier studies on yield in unthinned old-field plantations, have been generously supplied by the originators of the studies.[8] They should provide insight into the regional variability of the species and aid in the design of future data collection efforts.

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[6] Lenhart, J. D. 1968. Yield of old-field oblolly pine plantations in the Georgia piedmont. h.D. Dissertation, University of Georgia, thens, GA.

[7] Burkhart, H. E. 1973. Site index curves rom stem analysis data. Supplement to VPI-ndustry Cooperative Yield Study Rept. #6, unblished memo.

A large data set from thinned, old-field plantations has been supplied to the Cooperative by the Virginia Division of Forestry for analysis and research purposes. These data come from over 100 remeasurement plots on private landholdings in piedmont and coastal plain Virginia. Many of these plots are now approaching 50 years of age. All have been thinned at least once and several have been subjected to multiple thinnings. Variables recorded include dbh by one-inch classes, total height and mortality by causal agent. These data have not been analyzed previously and hopefully will add insight into the effects of thinning on old-field plantation growth and development.

Additional data from thinned old-field stands in Maryland, Virginia, North Carolina, South Carolina and Georgia have been obtained through a cooperative agreement with the North Carolina State Forest Fertilization Cooperative. These plots were initially thinned and then individual trees were measured and tagged. Subsequent remeasurements occurred after two and after four years.

Past studies on growth and yield of unthinned, old-field loblolly pine plantations have largely covered the natural range of the species (for example, Burkhart et al. 1972, Goebel and Warner 1969, Lenhart 1972, Lenhart and Clutter 1971, and Smalley and Bailey 1974), but there is relatively little data on thinned stands or stands planted on non-old-field sites. The Loblolly Pine Growth and Yield Coop is currently analyzing those plot data that are available from thinned stands on old-field sites and making plans to collect new data in cutover, site-prepared plantations.

Proposed New Data Collection

Our surveys of existing data from loblolly pine plantations have revealed adequate sources for old-field sites but there is a paucity of data from cutover, site prepared lands. For over a decade a large portion of the plantings have been on cutover rather than old-field lands. Many of these plantations on cutover sites are now of sufficient size to consider thinning, but adequate growth and yield models for evaluating the complex biological and economic tradeoffs involved in decisions about thinning are not available.

Because of the importance of growth and yield information for both thinned and unthinned plantations on cutover lands, the Cooperative has developed plans for a regionwide set of permanent plots. These plots will be established in unthinned stands and then thinning treatments will be imposed. Initial measurements and remeasurements of the control plots will provide data for the development of growth and yield equations for unthinned conditions. The plots that will be thinned will have initial conditions similar to those of the control plots. Thus, direct comparisons of thinned vs unthinned stand development should be possible.

As a future data collection goal, we hope to supplement the data gathered in existing plantations with a set of spacing experiments. Designed spacing experiments are needed to help define juvenile growth and mortality, optimal density for given product objectives, and density effects on diameter and height growth. Information on density effects on height growth can be invaluable for assessing the adequacy of our current site index methods which assume density independence.

Few spacing experiments have been initiated and monitored over long periods of time because of the large land area and quantity of work required. The broad resources of land and personnel that are available to the Cooperative through its members provide a unique opportunity to initiate and continue such a study.

Prediction Methodology

Although a considerable amount of forest yield research has been conducted, there is still a need for better yield estimates. Projection systems that are flexible for a wide range of management alternatives and utilization options, and that provide consistent and logical estimates of yield for varying amounts of stand detail, are needed. Daniels et al. (1979) compared three models for loblolly pine -- a whole stand model, a diameter distribution model, and an individual tree model -- and noted that all performed similarly for simple yield estimates. The more detailed individual tree model, while providing greater detail and flexibility, was much more expensive to execute than the diameter distribution or whole stand models. Although guidelines are given for the efficient use of these models, there is no overall unifying structure and incompatible growth and yield estimates may result whe the models are interchanged.

The Loblolly Pine Growth and Yield Coop at Virginia Tech is striving to develop a forest growth and yield projection system that is sufficiently flexible to account for the effects of intensive cultural practices, with output sufficiently detailed (complete diameter and height distributions) to allow for analyses of a full range of utilization options. This system shoul capable of providing logical and consistent stimates of growth and yield for varying degrees stand detail (whole stand values, estimates diameter class, or individual tree figures), us allowing users to efficiently compute esti- tes with stand detail appropriate to the use the information.

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[8] The cooperation of Drs. Russell Ballard, North Carolina State University; Jerome L. Clutter, University of Georgia; J. David Lenhart, Stephen F. Austin State University; and Alfred D. Sullivan, Mississippi State University, in supplying data for use in regional analyses is gratefully acknowledged.

The highest order model (i.e, greatest ount of detail or resolution) will have a ructure similar to that of the loblolly pine antation simulator published by Daniels and rkhart (1975). In such a model, the diameter owth, height growth, and survival probability individual trees are simulated as a function an initial growth potential and an index of mpetition from neighbors. The competition in- x, based on a function of the size of and dis- nce to surrounding trees, is a measure of the gree to which growth resources may be limited the number and proximity of neighbors.

When progressing from a distance-dependent dividual tree model to one that does not re- ire information on intertree distances, some and-level generalization of the individual tree mpetition index is needed. One index that has readily interpretable stand-level generaliza- on is the area potentially available (APA) rown 1965, Moore et al. 1973). To compute APA, lygons are constructed around each tree by the tersection of lines which divide the distances tween neighbors. Mean APA, or average area per ee, is estimated by the inverse of the number trees per unit area. The use of APA as an dividual tree competition model and trees per re as the stand-level generalization is cur- ntly being investigated.[9]

Bailey (in press)[10] has recently shown that, considering transformations of variables which eserve an assumed probability density functional rm for describing diameter distributions, tree ameter growth models can be derived. These sults provide a link between tree-level growth dels and stand level diameter distribution dels. In 1975 Strub and Burkhart (1975) de- ved a class-interval-free method for obtaining pected yields from diameter distributions, thus oviding a mathematical link between diameter stribution and whole stand modeling approaches. ese results, along with those from current research, will be applied when completing the integrated spectrum from an individual tree model with intertree distances specified, to an individual tree model without intertree distances required, to a diameter class model, to a whole stand model.

We are also conducting research on deriving diameter distributions (which can be approximated with a probability density function) from stand average parameters. This will allow approximation of a diameter distribution when only overall stand values such as total cubic volume and total basal area are known.[11] Flexible methods for describing diameter distributions are also being investigated. Although probability density functions provide good approximations of diameter distributions in unthinned stands, they are not, in general, sufficiently flexible to account for all of the distributional shapes that can be created through thinning.[12]

SUMMARY

The Loblolly Pine Growth and Yield Research Cooperative at Virginia Tech consists of 10 industrial forestry firms and three public agencies. The objective of the Coop is to develop growth and yield methodology and estimates for intensively-cultured loblolly pine stands.

Existing data sources appear to be adequate to develop yield predictions for unthinned and thinned plantations on old-field sites. However, new data collection efforts are deemed essential to develop adequate predictions for thinned and unthinned plantations on cutover site-prepared lands. In addition to data collection in existing plantations on cutover sites, plans are being developed for a set of designed spacing experiments.

New methodology being developed in the Growth and Yield Coop centers around an integrated system of stand models that will allow consistent and logical estimates of yield for varying amounts of stand detail. A system capable of providing consistent estimates of growth and yield for varying degrees of stand detail (whole stand values, estimates by diameter class, or individual tree figures) would allow users to efficiently compute estimates with stand detail appropriate to the use of the information.

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[9] Daniels, R. F. An integrated system of and models for loblolly pine. Ph.D. Disser- ation (in preparation), VPI & SU.

[10] Bailey, R. L. Individual tree growth rived from diameter distribution models. rest Sci. (in press).

[11] Research being conducted by James R. Frazier, Graduate Research Assistant, VPI & SU.

[12] Research being conducted by Quang V. Cao, Graduate Research Assistant, VPI & SU.

LITERATURE CITED

Brown, G. S.
1965. Point density in stems per acre. Forest Research Institute, N. Z. Forest Service, Forest Research Notes No. 38, 11 pp.

Burkhart, H. E.
1977. Cubic-foot volume of loblolly pine to any merchantable top limit. Southern J. Appl. For. 1:7-9.

Burkhart, H. E., R. C. Parker, M. R. Strub and R. G. Oderwald.
1972. Yields of old-field loblolly pine plantations. Division of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University, FWS-3-72, 51 pp.

Cao, Q. V., H. E. Burkhart and T. A. Max.
1980. Evaluation of two methods for cubic-volume predictions of loblolly pine to any merchantable limit. Forest Sci. 26:71-80.

Daniels, R. F. and H. E. Burkhart.
1975. Simulation of individual tree growth and stand development in managed loblolly pine plantations. Division of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University, FWS-5-75, 69 pp.

Daniels, R. F., H. E. Burkhart and M. R. Strub.
1979. Yield estimates for loblolly pine plantations. J. Forestry 77:581-583, 586.

Goebel, N. B. and W. R. Warner.
1969. Volume yields of loblolly pine plantations for a variety of sites in the South Carolina Piedmont. Clemson Univ., Forest Research Series No. 13, 15 pp.

Kozlowski, T. T.
1971. Growth and development of forest trees. Vol. II. Academic Press, New York, NY, 514 pp.

Larson, P. R.
1963. Stem form development of forest trees. Forest Sci. Monograph 5, 42 pp.

Lenhart, J. D.
1972. Cubic volume yields for unthinned old-field loblolly pine plantations in the Interior West Gulf Coastal Plain. Stephen F. Austin Univ., Texas Forestry Paper 14, 46 pp.

Lenhart, J. D. and J. L. Clutter.
1971. Cubic-foot yield tables for old-field loblolly pine plantations in the Georgia Piedmont. Ga. Forest Res. Council, Report 22 -- Series 3, 12 pp.

Max, T. A. and H. E. Burkhart.
1976. Segmented polynomial regression applie to taper equations. Forest Sci. 22:283-289.

Moore, J. A., C. A. Budelsky and R. C. Schlesinger.
1973. A new index representing individual tre competitive status. Can. J. For. Res. 3: 495-500.

Smalley, G. W. and R. L. Bailey.
1974. Yield tables and stand structure for loblolly pine plantations in Tennessee, Alabama, and Georgia Highlands. U. S. Forest Service, Research Paper SO-96, 81 pp.

Strub, M. R. and H. E. Burkhart.
1975. A class-interval-free method for obtaining expected yields from diameter distributions. Forest Sci. 21:67-69.

WHAT MEASURE OF STAND DENSITY IS BEST FOR GROWTH PREDICTIONS IN LOBLOLLY PINE PLANTATIONS[1]

H. Lee Allen and Howard W. Duzan, Jr.[2]

Abstract.--Stand density measures previously used for loblolly pine stands are reviewed and their ability to predict growth is compared. Because of its practical and theoretical advantages basal area is recommended as the measure of density for use in growth and response models. A stocking guide based on maximum net volume growth and basal area is presented.

INTRODUCTION

As the demand for wood products grows and the and base on which to produce the wood resource ontinues to diminish, management intensity is of ecessity increasing. Silvicultural practices uch as fertilization and thinning are becoming ore prevalent in pine plantations throughout the outh. An important aspect of intensive management is the development of models that predict he effect of various silvicultural treatments on rowth and subsequent yield. The knowledge gained rom these models will allow forest managers to pply the appropriate treatment to stands so that he maximum returns are realized.

The two most important factors influencing rowth and response potential in established stands re stand density and site quality. It is essenial that the measures used to quantify these actors are accurate and meaningful. This paper ill consider the problems associated with measures f stand density.

When considering stand density or stocking a relative measure of a "proper" stand density), wo questions arise. First, which stand density easures will adequately delineate stands having he same competitive status over a range of sizes nd number of stems? Second, how does growth response vary across stocking levels and what is the optimum density for a given silvicultural treatment?

CURRENT MEASURES OF STAND DENSITY

Over the years many measures of stand density and stocking have been developed for use in loblolly pine (Pinus taeda L.) stands. Some of the more common ones associated with tree diameter or number of stems include basal area, number of stems, and stand density indexes developed by MacKinney and Chaiken (1935), Stahelin (1949), and Westvaco[3]. The development of most measures of stand density are based on the premise that a relationship exists between crown diameter or area and competition. Various techniques are then used to transform this relationship into a number of stems-diameter expression.

Reineke (1933) was one of the first investigators to approach the problems of accurately defining stocking of even-aged stands. The stand density index developed by MacKinney and Chaiken (1935) was an adaption of his ideas specifically to loblolly pine. In 1940, Chisman and Schumacher (1940) proposed a tree-area ratio as a measure of density. Stahelin (1949) used this ratio to develop his stand density index. More recently, Westvaco[3] has developed a stocking chart based on a crown diameter-dbh relationship for trees in fully-stocked stands.

Although the forms of the stand density indexes vary, they can be easily compared by presenting them as number of stems-diameter relationships

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[1] Paper presented at Southern Silvicultural esearch Conference, Atlanta, Georgia, November -7, 1980. Paper No. 6679 of the Journal series f the North Carolina Agricultural Research Serice, Raleigh.

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[3] Owens, E.G. 1970. Loblolly Pine Stocking Westvaco Research Report 47. Summerville Research Center, Summerville, SC (unpublished).

(fig. 1). For comparison purposes the stand density curves are represented by what their respective authors deemed as fully or 100% stocked. The shape of the curves (fig. 1) reflect the number of stems-diameter conditions which represent equal competitive status (question 1). These equi-competition curves represent various levels of stocking and are used to describe an optimal level for various silvicultural practices (question 2).

The shape of the equi-competition curves or stocking lines is very important since this shape determines how stands in different stages of development are classed as being of the same competitive status. The derivation of this shape for all the present stand density indexes is based on empirically derived relationships using data collected in subjectively chosen fully-stocked stands. Obviously any bias in selecting fully-stocked stands over the range of sizes and number of stems would influence the shape of the curves. It seems plausible that some underlying biological relationship would define the shape of these curves and would remove the necessity of fitting them with data from a subjectively determined stocking level.

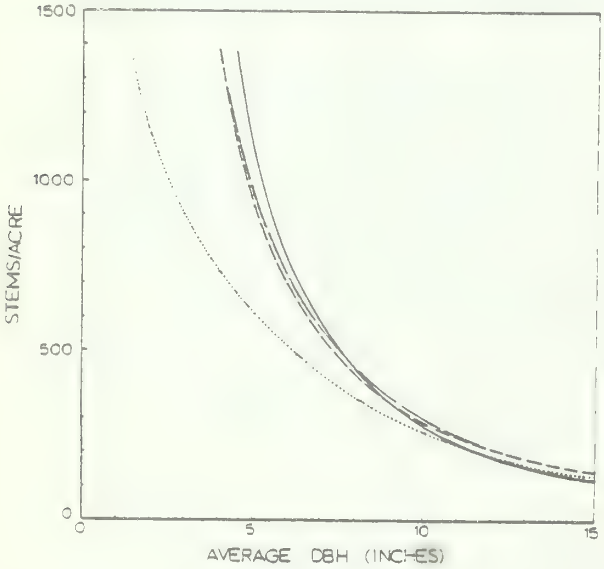

Figure 1.--Comparison of stand density indexes at fully stocked conditions:
— — — MacKinney and Chaiken (1935),
—— —— Stahelin (1949),
.... Westvaco (Owens, Unpublished),
———— Basal area of 150 ft^2/acre.

EQUI-COMPETITION CURVE SHAPE DERIVATION

The concept of the -3/2 power law or dimensional analysis recently introduced into the American forestry literature (Drew and Flewelling, 1977) provides a theoretical framework for defining the shape of these curves. The approach used in this paper follows that of Drew and Flewelling (1977).

Ground area (GA) for an individual tree is proportional to the inverse of the number of tree per acre (N) and also proportional to a length (L squared.

$$GA \propto 1/N \qquad (1)$$
$$GA \propto (L)^2 \qquad (2)$$

Tree diameter (D) is proportional to a length.

$$D \propto L \qquad (3)$$

It then follows that:

$$GA \propto (D)^2 \qquad (4)$$

Substituting 1/N for GA (equation 1), equation 4 may be rewritten as:

$$N \propto (D)^{-2} \qquad (5)$$

Statistically this may be expressed as:

$$N = K(D)^{-2} + \text{error} \qquad (6)$$

where K is a proportionality constant. Transform equation 6 becomes:

$$LogN = K' - 2LogD \qquad (7)$$

This is recognizable as the same form of MacKinne and Chaiken's (1935) stand density index except that the slope is a theoretically defined -2 instead of MacKinney and Chaiken's (1935) empirically derived slope of -1.707. The K' component determines the level of the curve and sets the standard reference for determining the number of stems at a given stocking level for a particular average tree size.

Since basal area (BA is proportional to average diameter, equation 7 can be expressed as:

$$LogN = K'' - LogBA \qquad (8)$$

On a theoretical basis equations 7 and 8 define shape of the number of stems-diameter relationsh as the square of diameter or more specifically curves of equi-competition have the same basal a

Theoretically from dimensional analysis, it appears that basal area is a suitable method of delineating stands with equi-competition or of t same stocking level. Traditional criticisms of basal area as a measure of stocking are: 1. ba area is one dimensional and does not adequately describe the relationship between number of sten and diameter, and 2. basal area should increase as tree size increases at a given stocking level. Referring to figure 1 it is apparent that basal area is two dimensional and expresses a dimensic relationship between number and size of stems. I fact, two of the empirical measures closely fol the basal area trend (fig. 1). For some species basal area may be expected to increase as tree creases for a given stocking level as some of a ree's basal area becomes nonfunctional. This is rne out in studies that have shown that sapwood rea may be a better estimator of foliage biomass rowth potential) than simply diameter or basal rea (Grier and Waring, 1974; Snell and Brown, 978). For loblolly pine of the size and age range und in managed plantations, total basal area is nerally equivalent to sapwood area.

UTILITY IN GROWTH PREDICTIONS

Putting theoretical considerations aside, ich of the stand density measures will best pre-ct growth response?

Three growth models were used to compare the ility of each stand density measure for predict-g gross growth of untreated stands.

) Gross Growth = a + b (SD)

) $\text{Gross Growth} = \dfrac{a + SD}{b + c(SD)}$

) $\text{Gross Growth} = \dfrac{a + SD}{b + c(SD) + d(SI) + e(SD * SI)}$

ere SD = stand density measure, SI = site index 5 years), and a, b, c, d, e are coefficients timated from the data.

The models were fit using 5-year growth data om 247 control plots selected from the North rolina State Forest Fertilization Cooperative's rst and second regional trial series. This data t covers the range of ages, densities, and site asses commonly found in managed loblolly pine antations. The data set and models B and C are scribed in greater detail in another paper pre-nted at the symposium (Duzan and Allen 1980). e coefficients of determinations for these three dels using the various stand density measures e as follows:

	-----------Model-----------		
	A	B	C
Basal Area	44.6	47.5	65.7
MacKinney and Chaiken (1935)	45.0	48.1	67.0
Stahelin (1949)	45.0	48.3	67.7
Westvaco[3/]	42.9	46.9	70.0
Number of Stems	16.8	8.1	34.1

All stand density measures, except number of ems performed equally in predicting 5-year gross owth of untreated stands. Nelson and Brender 963) reported similiar results in their compari-n of stand density measures. From a practical aspect, basal area is superior since it is easily understood, easily measured, and normally available for most managed plantations. Because of its theoretical and practical advantages, basal area is recommended as the standard for quantifying stand density in loblolly pine plantations.

OPTIMUM STOCKING LEVELS

Answering the second question of what stocking level is optimum for a given silvicultural treatment is more complex. The optimum stocking can be expected to vary depending on the treatment, site quality, response period, and management objectives. As a first approximation, a stocking guide based on maximum 5-year net volume growth and initial basal area is presented in table 1. A model estimating the ratio of 5-year mortality volume to 5-year gross volume growth as a function of basal area was used in conjunction with the gross growth-basal area-site index model to predict 5-year net volume growth.

This stocking guide delineates the basal area at which maximum net growth is realized in untreated plantations. Depending on the silvicultural treatment imposed, basal area as a measure of stand density may or may not reflect the potential for growth response in treated stands. For those treatments which do not substantially alter a stand's natural competitive structure, such as nitrogen fertilization, the stocking guide should be applicable for determining those stand conditions where maximum net volume growth occurs. However, if a stand's natural competitive structure was altered, as with thinning, basal area may not adequately express a stand's competitive condition after treatment. The deviation in volume growth of a thinned stand from that of an untreated stand of the same basal area will be a function of the type of thinning, thinning intensity, residual spacing, and the amount of damage to the site and residual trees during the thinning operation. Adjustment factors to compensate for these effects are discussed in more detail in another paper presented at this symposium (Ballard et al, 1980). After thinning, a stand will readjust to a more natural competitive status over time. Consequently, the deviation in growth of a thinned stand from that expected for an untreated stand will decrease over time and an adjustment factor may not be necessary for stands thinned several years previously.

If the stocking guide (table 1) was presented in the traditional number of stems-diameter format, it would be immediately apparent that the stocking levels are not proportional as typically portrayed in stocking charts. In fact, basing stocking on percentage of maximum net growth attainable, a large range of basal area provides the necessary resource to maintain stocking at 90 percent.

The basal area associated with maximum net growth decreases as site index increases. At first glance, this would appear to be contrary to what is normally expected. It is important to distinguish between the concepts of what basal area a given site can support and what basal area provides for maximum net growth. In the case of managed loblolly pine plantations, the basal areas associated with each concept probably differ; in fact, stands on higher sites would normally support greater basal areas.

CONCLUSIONS

Basal area is recommended as the measure for quantifying stand density in the development of growth prediction models for untreated loblolly pine plantations. Basal area has practical and theoretical advantages as a measure of stand density which are unequaled by any other currently used index. The use of basal area will provide an easy means of developing stocking guides based on different growth or response criteria using models currently available in the literature. A stocking guide developed using the percentage of maximum 5-year net volume growth attained as a stocking criteria illustrates that 90 percent stocking is associated with a wide range of basal areas. The basal area of a 100 percent stocked stand also decreases as site index increases. The stocking guide presented has been developed for growth prediction in untreated stands. The guide should still be valid for stands receiving treatments which do not substantially alter the natural competitive structure of a stand such as N. fertilization. However, the use of the stocking guide for stands receiving treatments which do substantially alter their structure, such as thinning, may not be valid.

Table 1.--Basal area stocking guides based on maximum five-year net volume growth for loblolly pine by site index class (25 year).

Percent of Maximum Net Growth	Site Index Class (ft)			
	50	60	70	80
		ft^2/acre		
50	10	10	10	5
60	20	20	15	10
70	30	30	25	20
80	45	40	40	35
90	70	65	60	55
100	125	125	120	115
90	180	180	180	175
80	200	200	200	195

LITERATURE CITED

Ballard, R., H. W. Duzan, Jr., and M. B. Kane.
1980. Thinning and fertilization of loblolly pine plantations. Paper presented at the Southern Silvicultural Research Conference Atlanta, Georgia, November 6-7, 1980.

Chisman, H. H. and F. X. Schumacher.
1940. On the tree-area ratio and certain of its applications. J. For. 38:311-317.

Drew, J. T. and J. W. Flewelling.
1977. Some recent Japanese theories of yield-density relationships and their application to Monterey pine plantations. For. Sci. 23: 517-534.

Duzan, H. W., Jr. and H. L. Allen.
1980. Estimating fertilizer response in site-prepared plantations using basal area and site index. Paper Presented at the Southern Silvicultural Research Conference, Atlanta, Georgia. November 6-7, 1980.

Grier, C. C. and R. H. Waring.
1974. Conifer foliage mass related to sapwood area. For. Sci. 20:205-206.

MacKinney, A. L. and L. E. Chaiken.
1935. A method of determing density in loblolly pine stands. U. S. Dept. Agric., For. Serv. Tech. Note 15, 3 p. Southeast. For. Exp. Stn., Asheville, N.C.

Nelson, T. C. and E. V. Brender.
1963. Comparison of stand density measures f loblolly pine cubic-foot volume prediction. For. Sci. 7:8-14.

Reineke, L. H.
1933. Perfecting a stand-density index for even-aged forests. J. Agric. Res. 46:627-638.

Snell, J. A. K. and J. K. Brown.
1978. Comparison of tree biomass estimators-dbh and sapwood area. For. Sci. 24:455-457.

Stahelin, R.
1949. Thinning even-aged loblolly and slash pine stands to specified densities. J. Fo 47:538-540.

A COMPETITION FUNCTION FOR TREE AND STAND GROWTH MODELS1/

William R. Harms2/

Abstract.--A two term function is described that is significantly correlated with annual diameter growth of individual loblolly pine *(Pinus taeda* L.*)* trees. One term expresses competition in the whole stand; the other is a measure of the competitive advantage of individual trees. The function operates by reducing the effective growing space of a tree, defined as the space available per tree in stands that are actively self-thinning.

INTRODUCTION

Computer simulation is a relatively new technique for studying tree growth and stand development. Mathematical models are the heart of simulation, and, of the types that have been proposed, the more interesting and useful project growth of individual trees rather than the entire stand. There are two types of these single-tree models: one requires information about the physical location of each stem in the plot or stand and is called a distance-dependent model; the other requires only a list of tree diameters and is called a distance-independent model (Munro 1974).

Both single-tree models project growth of individual trees according to some function of their size and competitive status in the stand. One approach is to adjust an assumed or estimated potential growth rate for a tree of given age or size by a component that gauges the intensity of competition. Another approach is to predict actual growth with a regression equation that contains a competition component.

In the distance-dependent model this component may be a competition index that relates d.b.h. or crown size to distance between the subject tree and its competitors. The competitors are chosen by a rule based on size and distance from the subject tree. In the distance-independent model the competition component usually expresses the relative position of a tree in the stand based on its d.b.h. in relation to some reference d.b.h.

The component that estimates competition is an essential part of single-tree models. It controls diameter and height growth and helps determine mortality. Various forms have been proposed, but none have yet proved to be entirely satisfactory (Alder 1979, Alemdag 1978, and Daniels 1976). All have failed to predict diameter growth with the desired precision and accuracy.

In this paper, I describe a new measure of competition. It is a mathematical function for the distance-independent model, but it also can be adapted to distance-dependent models. Development of this function is in a preliminary stage but, as the correlation data given below show, it has promise of becoming a useful addition to growth modeling.

THE COMPETITION FUNCTION

Underlying assumptions for the function are: (1) rate of growth depends on growing space, S_i, and (2) competition from its neighbors reduces the effective growing space of a tree to a fraction of the space available to it. The function, $f(S_i)$, estimates this fraction; for the *i*th tree, diameter growth, DG, can be estimated by a regression equation of the form:

$$DG_i = b_0 + b_1 (S_i)(f(S_i)) \qquad (1)$$

where S_i is growing space area of a tree defined as a function of d.b.h. The rationale and derivation of S_i and $f(S_i)$ are as follows.

Figure 1 shows typical development of pure, even-aged stands of loblolly pine. These data are from a study of the effects of extreme density on stand growth (Harms and Langdon 1976). The figure shows quadratic mean stand diameters for ages 6 through 20 years plotted over surviving numbers of trees in stands having initial densities

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1/ Paper presented at the Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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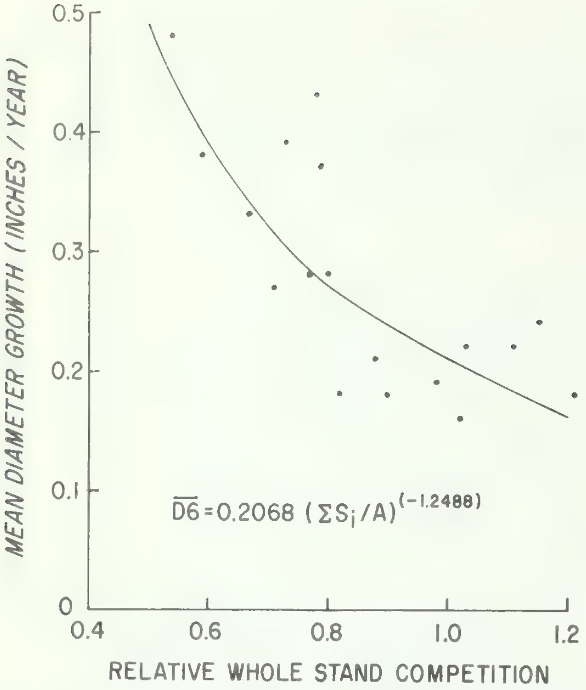

Figure 2.--Mean annual stand diameter growth of loblolly pine at age 14 in relation to stand level competition expressed in terms of the critical growing space, $\Sigma S_i/A$.

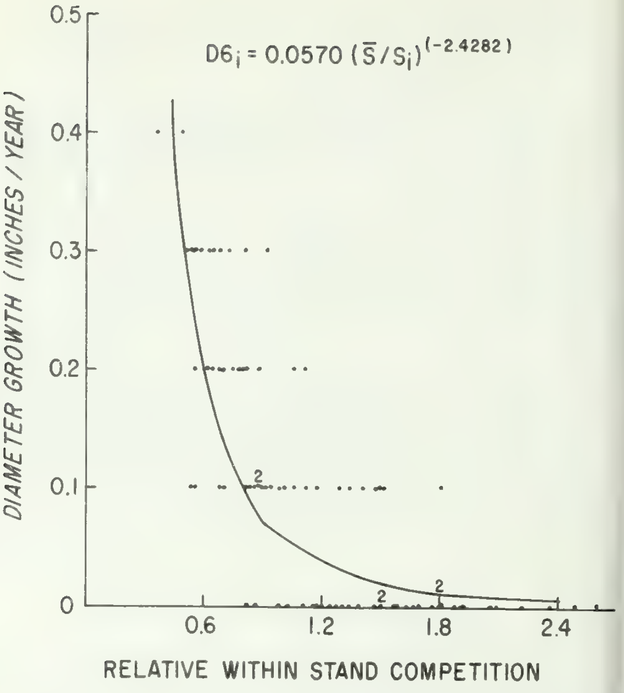

Figure 3.--Annual tree diameter growth of loblolly pine at age 18 in relation to within stand competition, $\bar{S}/S_i$.

The relationship of individual tree growth rate to the second component, $\bar{S}/S_i$, is shown in figure 3 for data from the 16,000-tree plots at age 18. A regression of the form

$$\text{Log}_{10}DG_i = b_0 + b_1\text{Log}_{10}(\bar{S}/S_i) \qquad (5)$$

where the variables are as defined above, was fit to the data. The regression was also significant at the 1% level and had an r^2 value of 0.57. The curve with its equation is shown in figure 3. There is a rapid decrease in diameter growth rate as the ratio, $\bar{S}/S_i$, increases to 1, which identifies the average critical growing space of the stand. At values greater than 1 growth becomes negligible as growing space decreases.

The form of the competition function is

$$f(S_i) = \left[1 + (\Sigma S_i/A)^{\phi_1}(\bar{S}/S_i)^{\phi_2}\right]^{-1} \qquad (6)$$

This particular form was suggested by Aikman and Watkinson (1980) and corresponds to the threshold response curves described by Thornley (1976). These are sigmoidal curves which describe plant growth responses to a critical growth factor. In the competition function, this growth factor is growing space, and the critical level is assumed to be the apparent critical growing space, S_i, per tree as defined by the self-thinning line.

The function approaches 1 as either of the competition terms approaches zero, indicating that there is little competition. It appraoche zero when $\Sigma S_i/A$ becomes 1 and $\bar{S}/S_i$ becomes larg indicating maximum competition for a tree in th lowest diameter class. The exponents ϕ_1 and ϕ_2 govern the severity of the effects of the tw components on growth rate.

TEST RESULTS

The competition function was tested by fitting equation (1) to annual growth data taken from the stands in figure 1. The product of t apparent critical growing space, S_i, and the co petition function, $f(S_i)$, is the independent variable and defines the effective or useable growing space of the individual tree. Separat regressions were fit to data from sets of plot having initial densities of 1000 and 16,000 tr per acre for stand ages 10, 12, 14, 16, and 18 years. The exponents of $f(S_i)$ were given the arbitrary values of 2 for ϕ_1 and 4 for ϕ_2. Al regressions were statistically significant at the 1% level. Table 1 presents values of the regression and correlation coefficients.

Most of the intercepts had values near ze and over half the slopes had values between 0. and 0.007. Differences among regressions, however, were significant. The correlation coefficients increased with age for both densitie because the large variation in growth of young stands tended to decrease as the stands got ol of 1000, 2000, 4000, 8000, and 16,000 trees per acre. The resulting curves show that as mean stand diameter increases with age, mortality induced by the intensifying competition for growing space gradually reduces the numbers of stems. At some point, depending on initial density, the relationship between mean d.b.h. and number of stems becomes linear on a log-log scale. The linear portion corresponds to the -3/2 power law proposed by Yoda and others (1963) to describe self-thinning populations of plants. The line is also equivalent to the stand density index relationship published by Reineke in 1933.

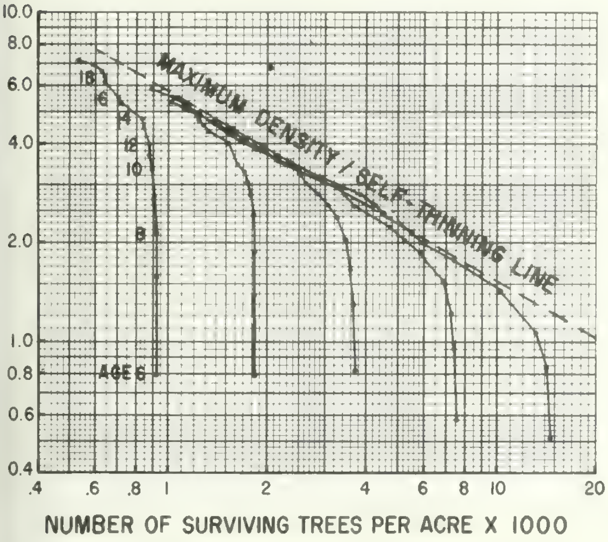

Figure 1.--Stand density-size relationships of self-thinning loblolly pine stands of initial densities of 1000, 2000, 4000, 8000, and 16,000 trees per acre for ages 6 through 21 years.

The self-thinning law implies that a plant of given weight or size requires a certain minimum growing space for its continued survival and development. As growing space falls below the minimum required, growth falls off and death eventually follows for some trees. The self-thinning line defines the apparent critical growing space S_i. The competition function is based on certain relationships that can be deduced from the self-thinning law.

For the loblolly pine data in figure 1, the self-thinning line can be described by the regression equation:

$$\mathrm{Log}_{10}\overline{D} = 2.5277 - 0.5896\ \mathrm{Log}_{10}(\rho) \qquad (2)$$

where $\overline{D}$ = quadratic mean d.b.h. and ρ = number of surviving trees per acre. The regression was fitted to data from plots having an initial density of 16,000 trees per acre and ages 10 thru 20 years. The mean apparent critical growing space, $\overline{S}$, is the reciprocal of the number of trees per unit area, ρ, and can be obtained by rearranging (2) so that

$$\mathrm{Log}_{10}\overline{S} = (-4.2871 + 1.6960\ \mathrm{Log}_{10}(\overline{D})) + \mathrm{Log}_{10}43560 \qquad (3)$$

where $\overline{S}$ is in units of square feet. The apparent critical growing space, S_i, of any tree, i, can be calculated by substituting D_i for $\overline{D}$ in (3).

Summing the estimated S_i over all the trees in a stand of area, A, yields the minimum growing space needed by the stand, ΣS_i. Dividing ΣS_i by stand area gives a measure of occupancy (relative stand density), $\Sigma S_i/A$. This ratio is one component of the competition function and expresses competitive status or stress for the stand. The ratio will take values from near zero at low site occupancy to 1 or slightly above at full occupancy. As the ratio approaches 1, competition becomes increasingly severe until at a value of 1 the stand reaches the self-thinning condition of a fully occupied site as represented by the self-thinning line.

Even under conditions of maximum competition, not all trees in an even-aged stand are competing equally. Larger trees are known to have a competitive advantage over their smaller neighbors, especially those in the lower crown classes. Consequently, a second component is necessary to account for differences in competitive advantage for individual trees. A simple way to express the position of a tree in the stand is as a ratio, $\overline{S}/S_i$, of the average critical growing space of the stand to the critical growing space of an individual tree. The value of the ratio increases from less than 1 for larger than average growing space to greater than 1 as growing space falls below average.

The two ratios $\Sigma S_i/A$ and $\overline{S}/S_i$ comprise the competition function. Their relationship to diameter growth is shown in figures 2 and 3. In figure 2, mean stand diameter growth at 14 years taken from the data in figure 1, is plotted over the corresponding value of $\Sigma S_i/A$. A regression of the form

$$\mathrm{Log}_{10}\overline{DG} = b_0 + b_1\ \mathrm{Log}_{10}(\Sigma S_i/A) \qquad (4)$$

where $\overline{DG}$ and $\Sigma S_i/A$ are defined as above, was fit to the data. The regression was significant at the 1% level and had an r^2 value of 0.60. Figure 2 shows the curve and its equation in exponential form. It is apparent that $\Sigma S_i/A$ is associated with a curvilinear decrease in mean stand diameter growth rate as the ratio increases to 1, the condition of maximum competition.

Table 1.--Regression coefficients for the competition function as fitted to selected diameter growth data.

Initial stand density	Coefficients	Age 10	12	14	16	18
no./acre		years				
	b_0	0.1811	0.0932	0.2184	0.0607	0.0327
1,000	b_1	0.0070	0.0064	0.0070	0.0041	0.0057
	r^2	0.33	0.28	0.34	0.51	0.47
	b_0	0.0324	0.0264	0.0821	0.0222	0.0069
16,000	b_1	0.0076	0.0119	0.0099	0.0077	0.0071
	r^2	0.18	0.39	0.38	0.55	0.65

and within-stand competition became more uniform. An example of the relationship is shown in figure 4 for age 18 and an initial density of 16,000 trees per acre.

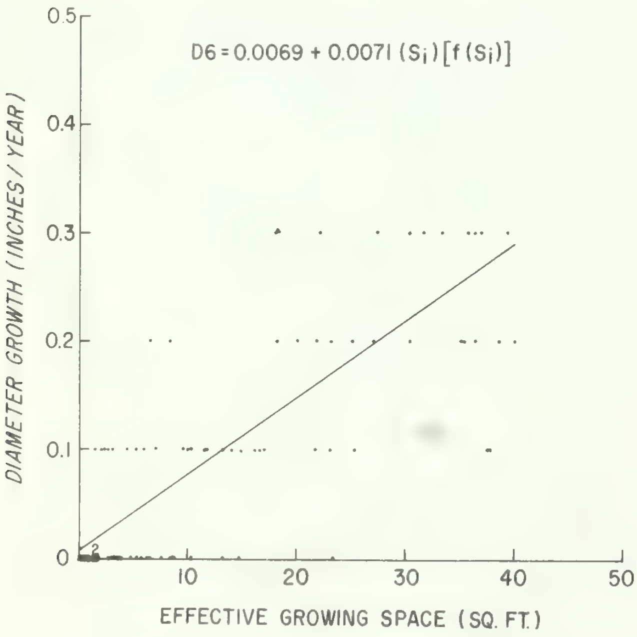

Figure 4.--Annual tree diameter growth of loblolly pine at age 18 in relation to effective growing space as estimated by the competition function, $f(S_i)$.

DISCUSSION

Only a few values for ϕ_1 and ϕ_2 have so fa been tested. For ϕ_1, in addition to 2, 4 was used and the value for the exponent for the var able, $\Sigma S_i/A$, in the regression shown in figure was tried. For ϕ_2, the values 4 and 8 were use The value for the exponent for the variable $\overline{S}/S$ in the regression in figure 3 was also tried. resulting regressions differed but little from those given in table 1.

In general, increasing the value of ϕ_1 wil increase the severity of the restriction on gro caused by stand competition as ΣS_i approaches t area of the stand. Increasing the value of ϕ_2, on the other hand, increases the severity of competition from neighboring trees. As ϕ_2 bec large, the competitive advantage of large trees over smaller ones increases rapidly. This fea of the function may permit adjustment or tunin of a growth model when its performance is bein evaluated.

In its present form, the function operate at the stand level; it does not account for lo competition experienced by a particular tree. Figures 3 and 4 show that there was considerab variation in the growth data used in the analy Trees of widely differing diameters often had same growth rate. It is likely that local com tition was responsible for some of this variat Possibly, some form of competition index can b incorporated into the function, or perhaps the terms can be modified to reflect more closely growing space relationships of a subject tree its competitors.

In conclusion, the preliminary tests of the function are encouraging. The two terms with their parameters may offer considerable flexibility in fitting it to different stages of stand growth and development. Further work is in progress.

LITERATURE CITED

ikman, D. P., and A. R. Watkinson
1980. A model for growth and self-thinning in even-aged monocultures of plants. Ann. Bot. 45:419-427.

lder, D.
1979. A distance-independent tree model for exotic conifer plantations in East Africa. Forest Sci. 25:59-71.

lemdag, I. S.
1978. Evaluation of some competition indexes for the prediction of diameter increment in planted white spruce, 39 p. Inf. Rpt. FMR-X-108. For. Mgt. Institute, Canadian For. Serv.

aniels, R. F.
1976. Simple competition indices and their correlation with annual loblolly pine tree growth. Forest Sci. 22:454-456.

arms, W. R., and O. G. Langdon.
1976. Development of loblolly pine in dense stands. Forest Sci. 22:331-337.

unro, D. D.
1974. Forest growth models--A prognosis, p. 7-21. In Growth models for tree and stand simulation. Research Notes No. 30. Royal College of Forestry, Stockholm, Sweden.

einеke, L. H.
1933. Perfecting a stand-density index for even-aged forests. J. Agr. Res. 46:627-638.

hornley, J. H. M.
1976. Mathematical models in plant physiology, 318 p. Academic Press, London and New York.

oda, K., T. Kira, H. Ogawa, and K. Hozumi.
1963. Self-thinning in over-crowded pure stands under cultivated and natural conditions. J. Biol. Osaka City Univ. 14:107-129.

SITE AND STAND FACTORS AFFECTING HEIGHT GROWTH CURVES OF LONGLEAF PINE PLANTATIONS[1]

William D. Boyer[2]

Abstract.--Some factors related to the form of height-over-age curves in longleaf pine plantations were identified from analyses of 660 periodically remeasured plots. Seventy percent of the variation among 32 plantations in form the growth curve was accounted for by stratifying planting sites into old fields, mechanically prepared and unprepared cut-over sites. Curve form was affected by site quality on prepared and unprepared sites, and by stand density on all sites.

INTRODUCTION

A major indicator of the productivity of southern pine plantations is site index at age 25 (SI_{25}), usually the mean height of dominant-codominant trees. Unfortunately, the early growth of southern pine plantations, including longleaf pine (Pinus palustris Mill.), is often so variable that use of a single set of site index curves has limited value at best and can be seriously misleading.

Often the predicted site index for a plantation changes over the years, whatever curves are used. Errors multiply as the time from index age increases (McGee and Clutter 1967). Even small errors in site-index estimates can cause large miscalculations of expected volume growth. For example, a change from 60 to 55 ft in SI_{25} reduces the projected cu-ft volume yield of a slash pine plantation at age 20 by 25 percent (Bennett et al. 1959).

Past studies suggest that height-over-age curves for southern pines established on old fields may differ not only between plantation and natural stand but also from similar stands established on cutover forest sites (Chapman 1938, Allen 1955, Bailey et al. 1973). Form of height-over-age curves may also be affected by other stand and site variables, particularly stand density (Bennett 1975, McClurkin 1976) and site quality (Beck and Trousdell 1973, Graney and Burkhart 1973).

For this study, height-over-age data from 66 remeasured plots, primarily the longleaf pine pha of the Southwide Pine Seed Source Study (SPSSS), were used to investigate how site and stand conditions affect early height growth of longleaf pin plantations.

METHODS

The SPSSS provided data from 637 of 660 remeasured plots in this study. The other 23 plots were from two separate studies in west Florida. Trees on all plots were scheduled for measurement at age 3 and 5, and at 5-year interv thereafter although the remeasurement schedule w not always strictly met. Some plots (136) were last measured at age 20, 21, or 22. The rest we last measured at age 15 except for 67 plots last measured at age 16 or 17. In all, there were 2737 height-over-age observations.

SPSSS series 1 and 2 (planted during winter 1952-53) and series 4, 5, and 6 (planted during winter 1956-57) were represented in this study, with 34 plantings in coastal states from Texas t North Carolina. Plantings were replicated at tw locations. Also, replicates were combined, maki a total of 32 recognized planting locations. Th parent study is described by Wells and Wakeley (1970).

At each examination, number of surviving tr and height of each survivor were recorded for in vidual plots. The mean height of the tallest ha of surviving trees on each plot was determined a represented the dominant-codominant fraction of the stand.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

[2] The author is Principal Silviculturist at the George W. Andrews Forestry Sciences Laboratory, Auburn, AL, maintained by the Southern Forest Experiment Station, Forest Service--USDA, in cooperation with Auburn University.

All plantations were classified into three roups according to planting-site condition: Old ields (283 plots and 1172 observations), mechanially prepared cutover forest sites (116 plots and 48 observations) and unprepared cutover forest ites (261 plots and 1077 observations). All bservations combined were given a stepwise egression analysis of the form:

$$\text{og}_{10}\ \text{Height} = b_o + b_1\ (\text{Age})^{-1/2} + b_2\ (\text{Age})^{-1} + b_3\ \text{Age})^{-2} + b_4\ (\text{Age})^{-3} + b_5\ (\text{Age})^{-4}.$$

he analysis determined which of the included ndependent variables would give the best singleariable regression.

The single variable regression model considered he best was fitted to the height-over-age observaions for each individual plot, resulting in 660 quations. Further analyses explored the relationhip of slope coefficients for individual plots, as dependent variable, to recorded site and stand ariables. These were primarily stand density surviving trees per acre at age 10), site quality height of tallest half of trees per plot at age 5), and the three planting-site conditions.

Coefficients for all 136 plots through age 0-22 were compared with coefficients derived from he same plots through age 15 only. Values of lope coefficients from plots through age 20-22 iffered from age-15 values by an average of only .7 percent. Plantation height-growth patterns in his study appeared to be well established by age 5, so all slope coefficients were pooled for nalyses without regard to plantation age at last easurement.

RESULTS

The best single variable regression for all 737 height-over-age observations was: Log_{10} HT = .8844 - 6.1764 $(\text{Age})^{-1}$. The coefficient of etermination (r^2) was 0.8484. The only other ariable contributing significantly (.05 level) to he regression was $(\text{Age})^{-4}$, which, when included the equation, resulted in an R^2 of 0.8497.

The model $\text{Log}_{10}\ \text{HT} = b_o + b_1\ (\text{Age})^{-1}$ was fitted each individual plot: 520 (79 percent) of the esulting equations had r^2 values of 0.99 or better. ope coefficients (b_1), with negative sign itted, became the dependent variable in analyses the relationship of planting-site condition, and density, and site quality to the form of rly plantation height growth.

Planting-to-planting and plot-to-plot variation slope coefficients was high. Classification of e 32 SPSSS plantation locations into the three anting-site conditions accounted for 70 percent the variation among plantings in average slope efficient. The mean, standard deviation, and nge of coefficient values for the 32 plantation locations are illustrated in figure 1 for each planting-site condition. Much of the remaining variation can probably be attributed to factors such as two different years of plantation establishment, varying sets of seed sources, and geographic location with its associated climatic and soil-site conditions.

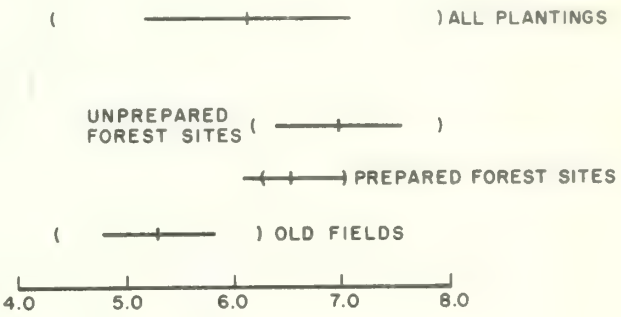


Figure 1.--Mean, standard deviation, and range of growth curve coefficients for plantings on old fields, prepared and unprepared forest sites, and all plantings combined.

Both stand density and site quality had a small but highly significant effect on growth curve coefficients. Classification into the three planting-site conditions alone accounted for 43 percent of plot-to-plot variation. Addition of stand density raised this value to 47 percent and site quality to 48 percent. Stand density affected growth curve form in each of the three planting site conditions. Site quality affected curve form only on prepared and unprepared sites, indicating that site index curves for these conditions will be polymorphic.

Planting-site condition had the greatest impact on curve form, with the largest contrast being between old fields and unprepared forest sites. The difference, for plantings with a stand density of 700 trees per acre, is illustrated in figure 2 for four site index (SI_{25}) classes. For SI_{25} of 60 ft, 10-year-old plantations on old fields are about 5 ft taller than similar plantings on unprepared forest sites. The comparatively rapid early growth on old fields can be attributed to less low competition than on unprepared cutover sites. Competition was primarily from shrubs and herbaceous vegetation because residual trees had been removed or killed in all plantations. The extreme of growth curve differences among individual plots is shown in figure 3. With a common SI_{25} of 50 ft, the difference in tree height at age 10 is 20 ft. The upper curve is an old field plot, the lower curve an unprepared forest plot. The regression r^2 values for each of these two plots were 0.999 and 0.994, respectively.

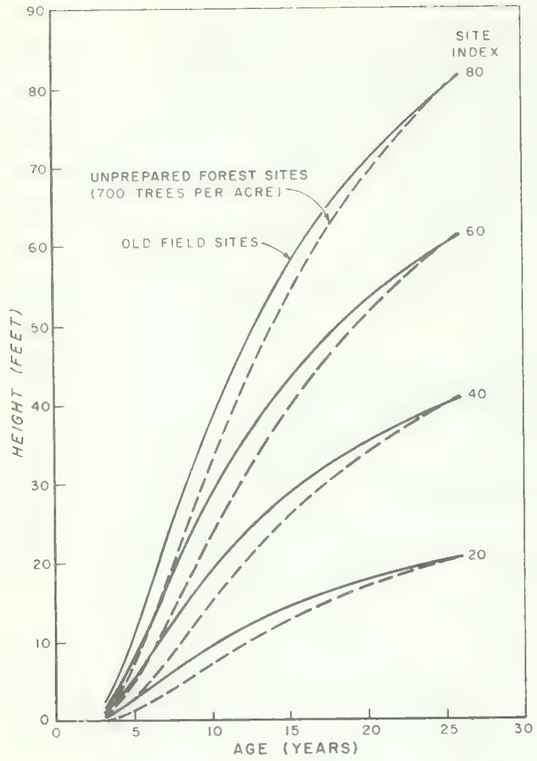


Figure 2.--Comparison of growth curves on unprepared forest sites with those on old fields for selected age 25 site index values.

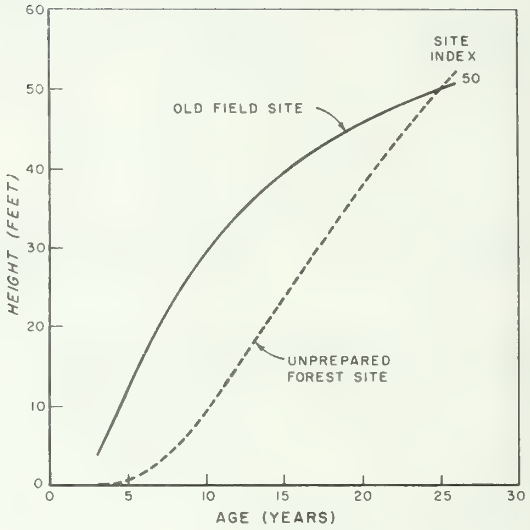


Figure 3.--Comparison of growth curves on two plo with greatest observed difference. Upper curve old field; lower curve-unprepared forest site.

Differences in growth curves between prepared and unprepared forest sites are not as great as those between old fields and unprepared sites (fig. 4). For SI_{25} of 60, 10-year-old trees on prepared sites have about a 3 ft height advantage over similar plantings on unprepared sites.

Growth curves for prepared forest sites were close to those of old fields on good sites, but differences increase as site quality declines (fig. 5). For SI_{25} of 80, there was no apparent difference in the curves, but for SI_{25} of 40, old field plantings at age 10 had about a 2 ft advantage over prepared site plantings. As noted earlier, site quality affected curve form on prepared sites, but not old fields, hence the opportunity to converge. On good sites, intensive mechanical site preparation resulted in growth equivalent to that expected on old fields. Even on poor sites, differences were relatively small.

The observed effect of stand density on curve form is illustrated in figure 6 for an old-field site, one with 250 and the other with 1200 trees per acre. Given the same SI_{25}, the curve for the high density stand is higher than that for the low density stand. The difference is not great, amounting to slightly over 2 ft at age 10 for SI_{25} of 60 ft. In this illustration, SI_{25} was set at an equal value for comparison of growth curves for each of the two stand densities. Early plantation growth for both densities on an equivalent site should be identical until canopies close. Afterwards heigh growth for the high density stand can be expected to fall below that of the low density stand.

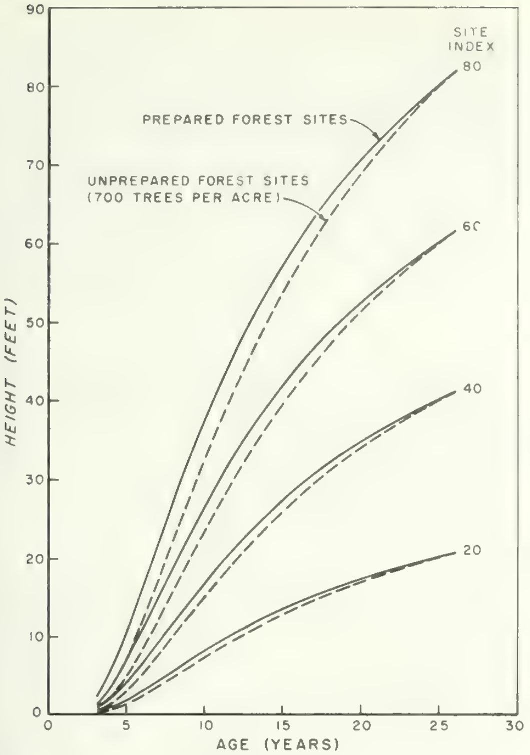
CONCLUSIONS

Results of this study indicate that form of height-over-age curves are influenced by planting site variables and stand density. The degree of intensity of preplanting site preparation apparently has the greatest impact on form of the height-over-age curves. It must be considered wh attempting to estimate site quality from early plantation height growth. Site quality per se affected curve form on both prepared and unprepa forest sites, suggesting that site index curves developed for these two conditions will be polymorphic. The stand density effect was highly significant but small. So within the range of densities expected in most plantations, it will a negligible effect and can be reasonably ignore

LITERATURE CITED

Allen, R. M.
1955. Growth of planted longleaf pine on cut land and old fields. J. For. 53:587.

Bailey, R. L., W. F. Mann, Jr., and T. E. Campbe
1973. Slash pine site index in the West Gulf. U.S. Dep. Agric. Forest Serv. Res. Note SO-16 4 p. South. Forest Exp. Stn., New Orleans, L



igure 4.--Comparison of growth curves on unprepared forest sites with those on mechanically prepared sites for selected age 25 site index values.

eck, D. E., and K. B. Trousdell.
1973. Site Index: accuracy of predictions. U.S. Dep. Agric. Forest Serv. Res. Pap. SE-108, 7p. Southeast Forest Exp. Stn., Asheville, N.C.

ennett, F. A.
1975. Slash pine: some intriguing growth and yield relationships. U.S. Dep. Agric. Forest Serv. Res. Pap. SE-133, 12p. Southeast. For. Exp. Stn., Asheville, N.C.

ennett, F. A., C. E. McGee and J. L. Clutter.
1959. Yield of old field slash pine plantations. U.S. Dep. Agric. Forest Serv. Stn. Pap. 107, 19p. Southeast Forest Exp. Stn., Asheville, N.C.

hapman, R. A.
1938. The effect of origin of stand on the site index of longleaf pine. J. For. 36:75-77.

raney, D. L., and H. E. Burkhart.
1973. Polymorphic site index curves for shortleaf pine in the Ouchita Mountains. U.S. Dep. Agric. Forest Serv. Res. Pap. SO-85, 12p. South. Forest Exp. Stn., New Orleans, LA.

cClurkin, D. C.
1976. Influence of spacing on growth of loblolly pines planted on eroded sites. U.S. Dep. Agric. Forest Serv. Res. Note SO-209, 4p. South. Forest Exp. Stn., New Orleans, LA.

cGee, C. E., and J. L. Clutter.
1967. A study of site index for planted slash pine. J. For. 65:491-493.

ells, O. O., and P. C. Wakeley.
1970. Variation in longleaf pine from several geographic sources. Forest Sci. 16:28-42.

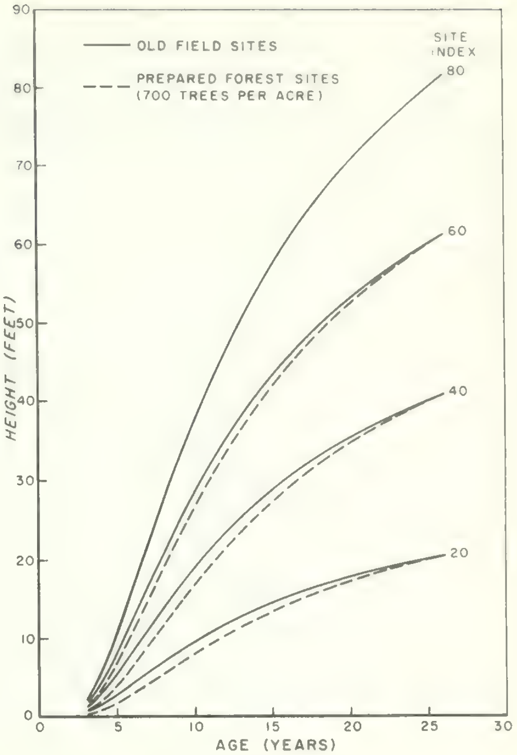


Figure 5.--Comparison of growth curves on mechanically prepared sites with those on old fields for selected age 25 site index values.

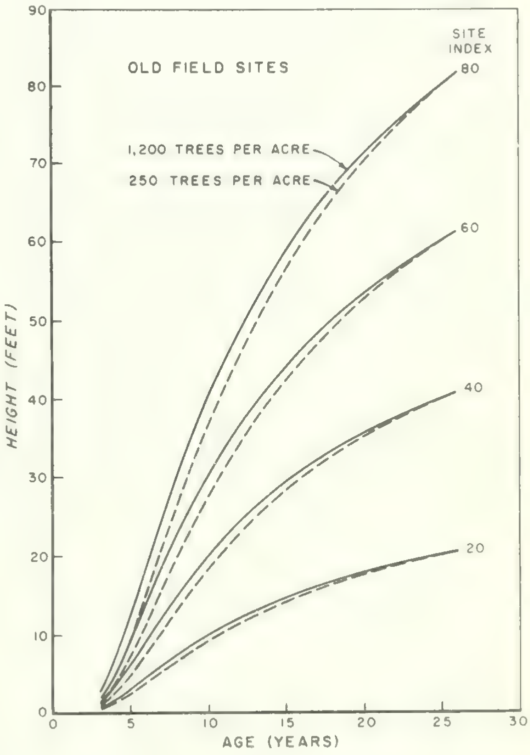


Figure 6.--Comparison of old field curves for plantings having 250 trees per acre, at age 10, with those having 1200 trees per acre.

SEEDLING SURVIVAL ESTIMATES USING 35MM AERIAL PHOTOGRAPHY: A NEW APPROACH[1]

Craig D. Campbell
and
Roy A. Mead[2]

Abstract.-- Seedling survival inventories for loblolly pine (Pinus taeda L.) plantations in eastern Virginia were performed by using small format, 35mm, color infrared aerial photography. The test sites selected were (1) chopped and burned or (2) K-G bladed, windrowed, and bedded. One year old plantations representative of both site preparation methods were tested. The photography was obtained during the winter of 1980 at several scales. Survival counts were made from the photos and compared with the counts made on the ground. Economic and accuracy comparisions were made between the photo and current industry field methods.

INTRODUCTION

The costs of regenerating the southern pines are increasing rapidly. As natural stands are harvested, they are being replaced by pine plantations. The livelihood of the forest industry in the Southeast depends on the successful regeneration of these plantations. To ensure their success, we protect this capital investment with intensive site preparation in an effort to control competing vegetation. Due to the size of this investment, most companies require that seedling survival estimates be made at the end of the first growing season. The purpose of this paper is to outline a proposed photogrammetric method for estimating seedling survival and compare it with the current methods used by the forest industry.

PHOTOGRAMMETRIC METHOD

There are several recent papers on photogrammetric procedures to estimate seedling survival (Nelson, 1977a and Schaefer, 1978). However, none of these incorporate the use of 35mm aeria photography, nor do they present an operational system to use with a photogrammetric procedure. One or more of the following points were found be deficient in the papers reviewed: (1) the cc for the ground surveys, (2) the sampling intens of the ground survey, (3) the costs for the phc grammetric survey, and (4) the amount of photo coverage obtained by the photogrammetric surve (Grumstrup and Meyer, 1977; Nelson, 1977a; and Schaefer, 1978). This section presents a proposed operational photogrammetric method and th experimental procedure which supports it.

Procedure

The experimental procedure for aerial pho acquisition involves the use of Kodak 35mm col infrared (CIR) ektachrome in conjunction with 35mm SLR camera with a 205mm telephoto lens. color shifting properties of the CIR film allo for better species discrimination and ease of terpretation over standard panchromatic and co films (Howland, 1980). A 205mm telephoto lens was chosen to minimize displacement while allc ing for safe flying heights at the scales of i terest. This procedure was used in an attempt image 1-0 loblolly pine (Pinus taeda L.) seedl after one growing season on intensively prepa sites. The aerial photography was taken duri March of 1980 because the maximum contrast between the annual and deciduous vegetation and evergreen vegetation exists during the winter months. The photography was obtained using th above system and a helicopter platform.[3] Th cales of photography were 1:300, 1:600, 1:740, :890, and 1:1040. On the plantations investiated,4/ at a scale of 1:300, 93 to 100 percent of ll seedlings were imaged on the film. On the ame sites, at a scale of 1:890, 84 to 90 percent f all seedlings were imaged on the film. Due to ne ability to image one year old loblolly pine eedlings with this procedure, an operational otogrammetric method using the procedure was esigned.

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[1] Paper presented at the Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

[2] The authors are Graduate Research Assistant and Assistant Professor, respectively, in the School of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061.

Proposed Method

The proposed operational method depends on ne integrated use of a 35 mm aerial photo ystem. Initial small scale vertical photography ould be flown and the photo detail transferred o a base map (e.g. U.S.G.S. quadrangles) to etermine the number of hectares for planting r site preparation payments. Standard transect ines and plots are then located for a given ampling intensity and their coordinate positions re recorded.5/ The transects are then flown ith large scale, vertical, aerial photography i.e. the photography described) and the seedling ounts are made directly from the slide projectons. The counts can be corrected to per hectare igures of seedling survival based on the apriori nowledge of the sample point coordinates, the lying height of the aircraft, the camera system, nd the initial number of trees planted per ectare. Using this information, the required alculations and actual mapping of seedling urvival for each plantation can be done by imple computer packages. The end product is contour map of survival percentages or numbers f trees per hectare for every plantation invenoried and a permanent film record of that nventory.

INDUSTRY METHODS

The current methods for estimating seedling urvival involve the use of fixed area plots hat range in size from 4.05 to 40.5 square meters. Depending on the area, the survival plots are allocated on a two to five plot per hectare basis with predetermined transects. However, industry cruises range from 0.05 to 2.0 percent and yield survival data which is referenced for each plantation in a coordinate or grid system. From the field data, the surviving number of trees per hectare are calculated and compared with the number of trees planted per hectare. The resulting survival percentages are transferred to a base map and areas of unacceptable regeneration are manually located. The disadvantage of these methods is that they require a relatively large number of man-hours (Nelson, 1977b).

RESULTS AND DISCUSSION

As previously stated, the objective of this paper is to compare and contrast the proposed photogrammetric survey with the current surveys used by the forest industry in the Southeast. It is proposed that the photogrammetric survey would take less time to complete than the same survey would on the ground. From information provided by industry cooperators6/, initial comparisons between the two methods are possible. A summary of their respective advantages and disadvantages follows.

The ground survey is the primary method used by the forest industry to evaluate seedling survival. The inventory methodology is simple, requiring only the enumeration of seedlings within a plot boundary. The industry survey also provides an opportunity for an on-site inspection of the quality of the planting and the general condition of the plantation. A major concern is the quality of this survey with respect to the investment it represents. Generally, the sampling intensity is very small and the plot locations are subject to bias or error.

The photogrammetric survey is also subject to several problems. The use of CIR film limits the time of day during which the photos can be taken because shadows (e.g. from low sun angles) on CIR film are completely black. Due to the oblique nature of the photography, competing vegetation (e.g., stump sprouts, sedges, and other annuals) caused problems by casting shadows on seedlings and by reducing the light reflected by the seedlings. The relative size or height of individual seedlings and/or their vigor (i.e. amount and color of foliage) were other problems with interpreting the imagery. The smaller or

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3/Earlier flights proved the fixed-wing lanes to be unsatisfactory for covering the stablished research plots due to inadequate light line control and tip. Due to the lack of helicopter mount these photos are low oblique xposures.

4/Two site preparations were investigated: a) A drum-chopped and burned plantation owned y the Chesapeake Corporation and (b) a windrowed nd bedded plantation owned by the Union Camp orp. (Franklin, Va.).

5/ The x and y coordinates are needed to ocate the sample point within the plantation nd the z coordinate or elevation of the point s needed to calculate the sample size.

6/The Chesapeake Corp., West Point, Va. and the Union Camp Corp., Franklin, Va. were willing and helpful cooperators and we extend them our gratitude.

less vigorous seedlings were often not interpreted. These problems accounted for all seedlings that were not imaged. It was found that the photo interpretation improved significantly (Bishop et al., 1975)[7] as the angle from the vertical was reduced. In other words, the closer the seedlings were to the nadir the better the interpretation. The remaining problem is one of misclassification of vegetation. Due to the design of the sample, no previous imagery of similar sites was available for training the photo interpreter. This often led to the classification of American Holly (*Ilex opaca* Ait.) as seedlings. In fact, they have quite different spectral signatures. Therefore an experienced photo interpreter could differentiate between the holly and the seedlings. Most of the problems associated with this method deal either with the non-vertical nature of the photography or the lack of training sets for the interpreter.

There are several advantages in using the photogrammetric method. Stand areas can be checked without ground surveys. The plantations need only be visited if the success of the plantation is in question. The aerial survey also allows for inspection of the quality of the planting and the general condition of the plantation. The aerial survey allows for increased sampling intensity over the ground surveys. This can range from two to forty times the intensity of current industry surveys. All manual work required to manipulate the cruise data can be done by computer and in less time. The final products not only tell which plantations have survival problems but where those problems are located within the plantation. The last advantage of the photogrammetric method is that it requires less time to complete than a comparable ground method.

The time and cost comparison of these methods is best illustrated by example (fig. 1). In working with the initial data, the aerial survey can be completed in one-third the time it takes two men to complete the same ground survey. However, the photo method costs more than the ground method (fig. 1).[8] The decision to use the photo method should be made by considering their relative sample intensities. If the photo sample intensity is twice that of the ground sample

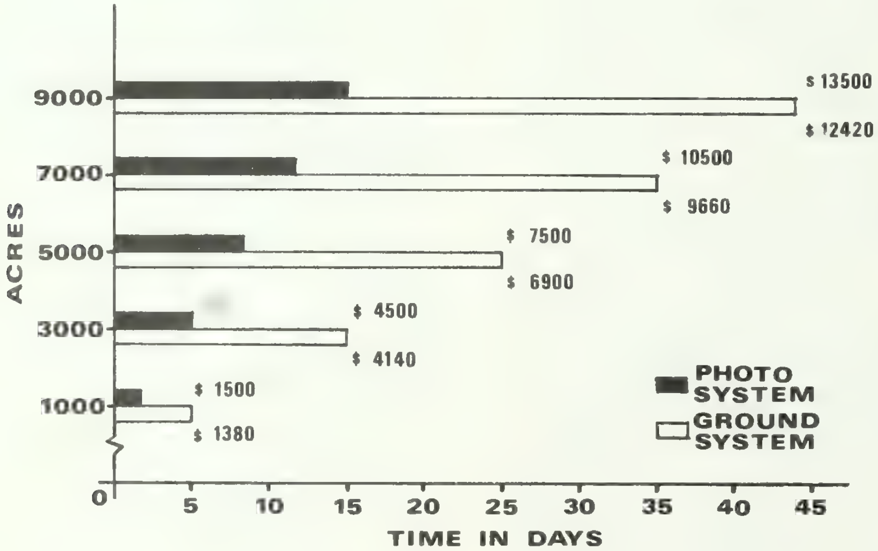

Figure 1.--Time and costs required to complete both the photogrammetric and ground surveys given the total number of acres inventoried.

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[7] Statistically tested by using discrete multivariate analysis at the 95% confidence level.

[8] The aerial survey includes film costs and developing, one man on full time (8 hrs/day), and the rental of a helicopter and pilot at $150/hr. for 4 hrs./day. The ground survey includes travel costs and two men on full-time (8 hrs/day).

intensity, the cost per unit of sample intensity (percent sample) for the photo method is approximately 54 percent of that for the ground method. Helicopter rental is the largest factor affecting the absolute cost of the photo method. However, the use of leasing plans or company ownership could easily reduce the absolute cost of the survey to less than that of the ground methods.

CONCLUSIONS

While there exist several problems with the photogrammetric method proposed in this paper, most of them can be solved with true vertical photography and a trained photo interpreter. The photo system is further justified by additional uses such as area determinations and other inventories. Also the photo method requires less time to complete the same inventory. The sampling intensity of the photo method may be two to forty times that of the current industry methods which in turn reduces the cost per unit of sample intensity. The end products for the photo inventory are more easily produced than by conventional surveys and the photos are a permanent record for each plantation. In this study, the absolute costs for the photo method are greater due to the cost of helicopter rental. However, reduction of this cost would reduce the absolute cost of the photo method so as to make it financially competitive with the ground method.

LITERATURE CITED

Bishop, Y., S. Fienburg, and P. Holland.
1975. Discrete multivariate analysis: theory and practice. MIT Press: Cambridge, Massachusetts. 575 p.

Grumstrup, P. D. and M. P. Meyer.
1977. Application of 35mm color and color-infrared aerial photography to analysis of fish and wildlife resources on disturbed lands. lands. In: Proceedings of the Sixth Biennial Workshop on Aerial Color Photography in the Plant Sciences. Colorado State University, Fort Collins, CO. Pages 81-89.

Howland, W. G.
1980. Mulitspectral aerial photography for wetland vegetation mapping. Photogrammetric Engineering and Remote Sensing. 46(1):87-99.

Nelson, H. A.
1977a. Assessment of forest plantations from low altitude aerial photography. In: Proceedings of the Eleventh International Symposium on Remote Sensing. Ann Arbor, Michigan. Pages 1515-1523.

Nelson, H. A.
1977b. Small format color photography for forest plantation planning in the Southeast. In: Proceedings of the Sixth Biennial Workshop on Color Aerial Photography in the Plant Sciences. Colorado State University, Fort Collins, Colorado. Pages 141-145.

Schaefer, E. L.
1978. Remote sensing for determination of seedling survival. In: Symposium of Remote Sensing for Vegetation Damage Assessment. American Society of Photogrammetry, Falls Church, Virginia. Pages 465-495.

COLOR AERIAL PHOTOGRAPHY AS A GUIDE TO FOLIAR NUTRIENT LEVELS AND SITE INDEX IN LOBLOLLY PINE PLANTATIONS[1]

Al Lyons and Edward Buckner[2]

Abstract. -- Color aerial photographs were obtained during the winter of 1979-80 of extensive areas of loblolly pine plantations in Franklin County, Alabama, and Wayne County, Tennessee. Photo interpreters identified 3 Munsell color classes that would accommodate the range of colors detected in loblolly pine plantations on these photographs. Each of these colors reflected a specific foliar nitrogen and site index range.

This technique permitted evaluation of productivity (site index) and foliar nutrient status from color aerial photographs, enabling more efficient land classification and possibly more efficient use of fertilizers for increasing productivity.

INTRODUCTION

The rapid expansion that has characterized the forest products industry in the South over the last decade has greatly increased the demand for roundwood, especially pine. To satisfy this demand, forest product industries are intensifying efforts to increase forest productivity on present ownerships rather than incur the high acquisition and maintenance costs of expanding their forest landownership. Fertilization provides one means of accomplishing this goal where suitable sites can be identified. Wide variations in response have demonstrated that care must be exercised in selecting plantations that will respond to increased nutrient levels.

Adequate foliar nutrient levels, especially N, usually result in dark-green foliage, the result of high chlorophyl concentrations. Chlorosis (yellowing) is commonly related to low foliar nitrogen levels (Pritchett, 1979).

Winter yellowing of loblolly pine (Pinus taeda L.) foliage, a common phenomenon throughout much of the South, has been related to foliar nutrient levels, especially N and P. Blinn (1978) color coded loblolly pine foliage to one of six discrete Munsell color signatures. As foliage color changed from yellow to dark-green there was a stepwise increase (highly significant increase) in both N and P. While positive correlations were found with both elements, the nitrogen relationship appeared most discrete. These high correlations between foliage color and nutrient concentrations suggest that color aerial photographs might be useful for determining foliar nutrient levels within and among loblolly pine plantations.

EXPERIMENTAL PROCEDURE

During the winter of 1979-80 color aerial photographs (0.4 um - 0.7 um) were obtained of loblolly pine plantations in Franklin County, Alabama, and Wayne County, Tennessee. Photographs were taken at 5,000, 10,000, and 15,000 feet using a Wild RC-10 camera mounted in a Cessna 411 Aircraft. Kodak Aerocolor Negative film 2445 (ester base) was used.

Rigid control over processing assured uniform color renditions on the various photographs. Three separate interpreters using acetate overlays drew boundaries between color classes that could be detected within loblolly pine plantations as seen on the color aerial photographs. These color units were then coded to a specific Munsell color chip.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980. Research funded by Champion Timberlands, Champion International Corporation.

[2] The authors are, respectively, Graduate Research Assistant and Associate Professor, Department of Forestry, Wildlife and Fisheries, The University of Tennessee, Knoxville, TN 37901.

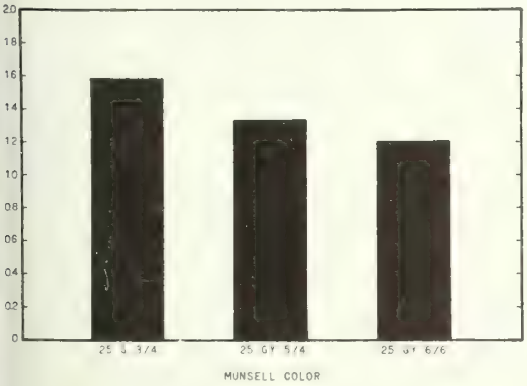
Ground truth was established by taking 3 lots in each color unit identified in a plantaion. At each sample plot, foliage was collected rom 4 trees and composited to make one sample. il samples were collected near each sample tree d composited to make one soil sample. Additional ta collected from each plot included (site index, sal area, average diameter growth over last 5 ears, aspect, and percent of slope).

Foliage samples were oven-dried at 70 degrees and ground in a Wiley mill to pass a 20-mesh reen. Nitrogen was determined by the Kjeldahl thod using a Tector distilling unit and titrator. was determined colormetrically, while K, Ca, d Mg were determined by atomic absorption ectrometry. Soil P and K and soil Ph were termined at the Tennessee Agricultural Extension rvice Soil Testing Laboratory.

RESULTS

Photo interpreters were able to identify 3 stinct color units in loblolly pine plantations: een (2.5 G 3/4), yellow-green (2.5 GY 5/4), and llow (2.5 GY 6/6). Although color shifts could detected in plantations at all 3 altitudes, e 5,000-foot photographs provided the best solution.

Foliar analysis revealed a significant lationship (.05 level) between foliar nitrogen vels and aerial photo color units (Figure 1) in ich foliar nitrogen in green areas averaged 58 percent, yellow-green areas averaged 1.33 rcent and yellow areas averaged 1.20 percent. liar P in green areas was significantly higher 05 level) than in the yellow-green and yellow eas; however, there was no significant difference the yellow side of the color range (Figure 2). significant correlations were found between liar K, Ca, and Mg and color units in loblolly ne plantations on these aerial photographs.



gure 1.--The relationship between foliar N and crown color determined from color aerial photographs.

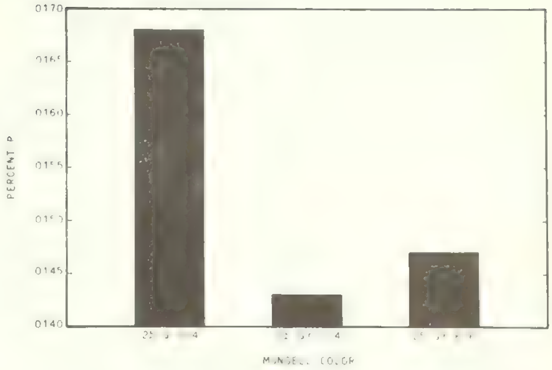


Figure 2.--The relationship between foliar P and crown color determined from color aerial photographs.

Soil analysis revealed a drop in P (Figure 3) and K (Figure 4) from green to yellow; however, only the decrease in soil P from yellow-green to yellow was statistically significant (.05 level).

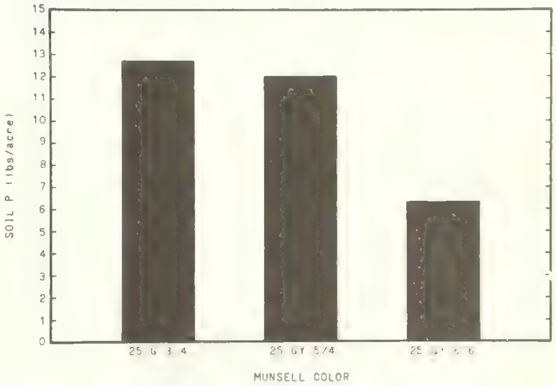


Figure 3.--The relationship between soil P and crown color determined from color aerial photographs.

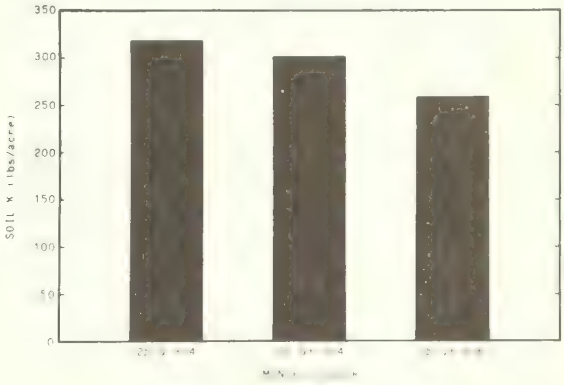


Figure 4.--The relationship between soil K and crown color determined from color aerial photographs.

Site index for loblolly pine ranged from a high of 100 (base 50) in the green areas to a low of 40 in the yellow areas. Average site indices for the 3 color units are: 90 for the green areas, 81 for the yellow-green areas, and 68 for the yellow areas (Figure 5). Stand basal areas decreased from 137 square feet per acre in green areas to 67 square feet per acre in yellow areas (Figure 6).

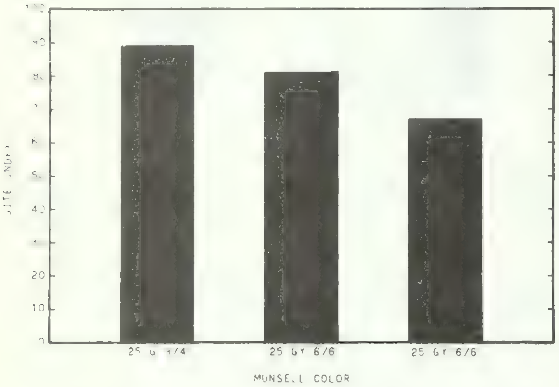


Figure 5.--The relationship between site index and crown color determined from color aerial photographs.

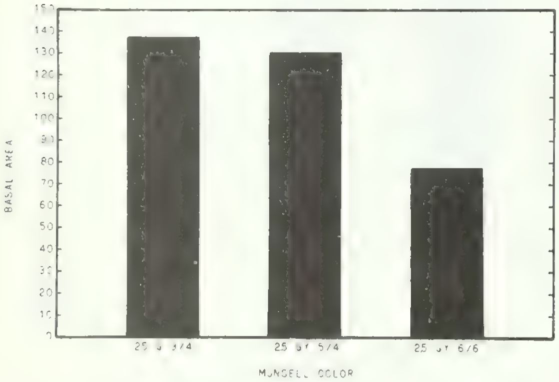


Figure 6.--The relationship between basal area and crown color determined from color aerial photographs.

DISCUSSION

Resource managers generally feel that research is needed to develop low cost applications of aerial photography to reduce expensive field measurements (Mead, 1980). The procedure described permitted the effective subdivision of loblolly pine plantations into categories based on: (1) nutrient levels, (2) site index, and (3) basal area.

Detection of foliar color units is possible from 10,000 feet (ratio 1:20,000) and 15,000 (1:30,000) provided visibility is approximately 40 miles. The use of 5,000-foot photography (ratio 1:10,000) reported here provided the most definitive results and photographs can be taken with visibility as low as 10 miles. Winter yellowing in loblolly pine generally occurs between December 1 and March 1; aerial photography for determining nutrient status should be restricted to this period. Photographs should be taken between 10:00 A.M. and 2:00 P.M. to minimize shadow effects, a serious problem in hilly terrain.

LITERATURE CITED

Blinn, Charles R.
1978. The Relationship Between Foliage Color and Foliar Nutrient Levels in Loblolly Pine. Unpublished Masters Thesis, Univ. of Tennessee

Mead, Roy A., and D. Ann Rasberry.
1980. Current Use of Remote Sensing by Foresters in the South. Southern Journal of Applied Forestry 4:143-147.

Prichett, William L.
1979. Properties and Management of Forest Soils. John Wiley & Sons, N.Y. 500 p.

FERTILIZER RESPONSE AND BIOMASS ACCUMULATION OF A 5-YEAR-OLD SWEETGUM PLANTATION[1]

Timothy T. Ku, John K. Francis, and Charles R. Blinn[2]

Abstract.--A sweetgum plantation was established in 1975 to evaluate the effects of N, P fertilizers on growth and biomass accumulation. Positive response to the N and, to a lesser degree, the N + P treatment were noted the first year after fertilization. At age 5, total biomass averaged 2.5 T/ha: 25% leaves, 25% branches and 49% stems. Biomass accumulation was 50% greater on N treated plots than control.

INTRODUCTION

Earlier trends and projections from wood sing industries indicated an increasing demand br hardwoods in the South. Hardwood plantations ave been established in recent years to meet such emand by Corporations mainly in the fertile alluval valley of the Mississippi River. Since land learing for farming has been proceeding steadily, he best sites available for hardwood timber prouction has diminished in the area. It is necesary, therefore, to turn to other sites for posible hardwood production.

In 1974, a cooperative study between the epartment of Forestry, University of Arkansas t Monticello and USDA-Forest Service was initiated o evaluate the potential production of hardwoods n a moderately poor silty upland site, a part f the University Experiment Forest. Sweetgum iquidambar styraciflua L.) was selected since t is one of the endemic hardwoods and a desirable pecies for both pulping and solid wood uses. ecause of the inherent slow growth of the sweetgum coupled with the low fertility of the soil, the objective of the study was to evaluate the effects of fertilizers on growth, nutrient accumulation and biomass production of planted sweetgum on a marginal hardwood site. This paper will not report the nutrient status since chemical analyses are incomplete.

METHODS

An old field of poorly-drained Henry silt loam, a coarse-silty, mixed, thermic, Typic Fragi aqualf was cleared of heavy brush and disked three times in late 1974. One-year-old sweetgum seedlings from an Arkansas source were hand-planted in February 1975, at 2.75 M x 2.75 M spacing. Fifty seedlings in 10 rows of 5 trees each were planted in each plot. The interior 24 trees were used as measurement trees to evaluate growth and stand development.

The statistical design was 6 randomized blocks of 4 fertilizer treatments: N, P, N + P and Control. Fertilizers were applied by a tractor drawn 4-foot-wide spreader in March, 1979 (at plantation age 4) at the rates of 280 Kg N, 168 Kg P, 280 Kg N + 168 Kg P per ha. No fertilizer was added on control plots.

Machine cultivation was maintained during the first two growing seasons to control competing vegetation. Survival of the planted seedlings was 81% at the end of the first growing season and they averaged 42 cm in total height.

Since 1977, the following measurements were taken: total height, diameter at 30 cm above ground, crown length and crown width. Beginning with the 1979 measurement, additional diameter at breast height measurement was taken when trees averaged more than 3 meters in height

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[1] Paper presented at Southern Silvicultural esearch Conference, Atlanta, Georgia, November -7, 1980.

[2] Timothy T. Ku is professor, Department of orestry, Agricultural Experiment Station, Univsity of Arkansas at Monticello. John K. Francis is il Scientist at the Southern Hardwoods Laboratory, ich is maintained at Stoneville, Mississippi, by e Southern Forest Experiment Station, Forest ervice--USDA, in cooperation with the Mississippi ricultural and Forestry Experiment Station and e Southern Hardwood Forest Research Group. arles R. Blinn was Research Assistant, Department Forestry, University of Arkansas at Monticello, now Research Assistant, College of Forestry, iversity of Minnesota, St. Paul.

In October 1977, one sample tree from each plot using the mean tree technique,[3] (a total of 24 trees) was harvested by shearing at the ground level for biomass and nutrient analysis. Each tree was separated into the following components: leaves, current branches, old branchwood, old branchbark, stemwood, and stembark. Components were weighed fresh and again after oven-drying at 70°C.

In October 1979, one growing season after fertilizer treatment, 6 trees from each treatment (one tree from each plot) covering entire ranges of height and diameter (dbh) were harvested. The change of population sampling technique was necessary to accommodate a greater range of tree sizes resulting from advanced stand development and crown differentiation.

RESULTS AND DISCUSSION

Fertilizer Response

Average values in height, diameter at 30 cm above ground, crown length and crown width for two years prior to fertilization (1977, 1978) and one year after fertilization (1979) are presented in Table 1. The sweetgum grew slowly at first. For the last year before fertilizer treatment (1978), the annual increments were: 92 cm in height, 1.1 cm in diameter at 30 cm above ground, 96 cm in crown length and 27 cm in crown width. It appeared that none of the average valu of the intended treatment plots were significantl different prior to fertilizer treatment.

Measurements in 1979, one growing season aft fertilizer treatment, showed that N and N + P plots made significantly more growth than Control or P only plots. On the average, treatments containing N increased height growth by nearly 30%, diameter growth by 25%, crown length by 20% and crown width by 61% (Table 2).

Biomass Accumulation

From the 1979 harvest, linear regression equations were derived from dry weights of felle trees in each treatment to estimate biomass accu mulation for that treatment. The regression equ tions followed the general form:

$$W = A + B\ (D^2H)$$

where W is the predicted biomass dry weight of individual tree, grams.
D is the dbh of the tree, mm.
H is the total height of the tree, cm.
A and B are the intercept and slope of the regression line.

Table 1.--A comparison of average height, diameter, crown length and crown width between fertilizer treatments.

Treatment	Height			Diameter at 30 cm			Crown length			Crown width		
	cm											
	'77	'78	'79	'77	'78	'79	'77	'78	'79	'77	'78	'79
N	163	259	353*	2.2	3.3	5.1**	135	233	318**	83	113	150*
P	162	257	329	2.2	3.4	4.8	135	235	292	83	111	138
N+P	159	245	341	2.0	3.0	4.7	132	220	299	77	100	137
C	155	247	321	2.0	3.2	4.6	123	219	287	81	107	130
Mean	160	252	336	2.1	3.2	4.8	131	227	299	81	108	139

** $P < 0.01$
* $P < 0.05$

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[3] Crow, T. R. 1971. Estimation of biomass in an even-aged stand--regression and "mean tree" techniques. in Forest Biomass Studies, XVth IUFRO Congress, University of Maine. pp 35-48.

Table 2.--First Year Growth Response to Fertilizer Treatments.

Treatment	Height		Diameter at 30 cm		Crown length		Crown width	
	cm	%	cm	%	cm	%	cm	%
N	94*	27	1.8**	29	85*	24	37**	61
P	72	—	1.4	--	57	--	27	17
N+P	96*	30	1.7	21	79	16	37**	61
C	74		1.4		68		23	

** $P < 0.01$
 * $P < 0.05$

Table 3.--Parameters of Biomass Prediction Equation by Fertilizer Treatments-1979 Harvest.

Treatments	Intercept (A)	Slope (B)	r^2
N	505.3266	.5629	.90
P	734.3317	.5202	.81
N+P	121.1416	.6913	.99
C	611.4199	.4577	.85

Table 4.--First Year Response of Biomass Accumulation by Fertilizer Treatments.

Treatment	Biomass				Periodic Increment		Periodic Annual Increment
	1977		1979				
	T/ha	%	T/ha	%	T/ha	%	T/ha
N	0.461	33	2.976*	48	2.515*	51	1.258*
P	0.496	43	2.688	34	2.192	32	1.096
N+P	0.424	22	2.513	25	2.089	26	1.045
C	0.346	--	2.007	--	1.661	--	0.830
Mean	0.432		2.546		2.114		1.057

*$P < 0.05$

From the regression equation constants presented in Table 3, biomass of each tree was calculated and summarized in Table 4.

Results from biomass sampling of 24 trees harvested in 1977 indicated these 3-year-old sweetgums have accumulated 0.432 T/ha of biomass (Table 4) with the following distribution of tree components: leaves 35%, branches 23% and stems 42% (Table 5).

On the biomass distribution of tree components as trees develop and age, there is apparently a shift toward greater accumulation in stems (Table 5). Foliage diminished from 35% of the total biomass at age 3 to only 25% at age 5, an indicati of increased photosynthetic efficiency with a greater accumulation of usable biomass in woody stems.

At age 5, biomass accumulation was 3 T/ha in N plots, 50% greater than the 2 T/ha accumulated in control plots. The periodic increment between age 3 and 5 was 1.26 T/ha/yr for the N plots and 0.83 T/ha/yr for the control. Total biomass averaged 2.5 T/ha for all plots. Additional analysis will be made to relate nutrient content and biomas to fertilizer treatments when nutrient data become available.

Table 5.--Change of Biomass Accumulation (%) by Tree Components With Time.

Tree Components	1977	1979
Leaves	35	25
New branches	11	4
Old branches	12	22
Crown	58	51
Stemwood	35	42
Stembark	7	7
Stems	42	49
Total	100	100

FERTILIZATION OF JUVENILE LOBLOLLY PINE PLANTATIONS
IMPACTS ON FUSIFORM RUST INCIDENCE[1/]

Michael B. Kane[2/]

Abstract.--Five-year results on the effect of fertilization of juvenile loblolly pine plantations on the subsequent incidence of fusiform rust (Cronartium fusiforme) are presented. Age at time of treatment, growth response to fertilization, and amounts of rust infection on non-treated plots during the period monitored varied substantially among the 41 stands evaluated. Fertilization had little pronounced effect on subsequent fusiform rust infection although some significant fertilizer-rust relationships were observed: P fertilization increased branch galls in stands responding strongly to P; fertilization with most elements, but in particular K, reduced the rate of rust infection in stands experiencing high levels of increased infection; and N fertilization reduced rust related mortality in stands responding strongly to N. However the magnitude of all these effects was small. Fertilizers can generally be applied to juvenile loblolly pine stands without penalty of substantial increases in fusiform rust.

INTRODUCTION

Fertilization of forest land in the Southeast hs received considerable attention in recent years. A comprehensive survey conducted in 1979 listed aproximately 450 studies examining fertilization o slash pine (Pinus elliottii var elliottii Engelm.) o loblolly pine (Pinus taeda L.) (NCSFFC 1980). Asociated with this substantial research effort hs been the increasing use of fertilizers in forest mnagement. Bengtson (1979) reported that approxiately 900,000 acres had been fertilized in the Sutheast through mid-1978.

While most forest fertilization research has fcused upon tree growth response, secondary effects o fertilizer applications have also been examined. Te influence of nutrient additons on the incidence of fusiform rust (Cronartium fusiforme Hedgc. & Hunt ex Cumm.) is of particular importance. Fusiform rust is the most serious disease problem affecting management of slash and loblolly pine in much of the Southeast.

Fertilization has been implicated with increased fusiform rust infection of slash and loblolly pine. Hollis et al. (1975) reported significant increases in rust on 11 of 25 slash pine plantations in the Lower Coastal Plain region with additions of nitrogen (N) and/or phosphorus (P) near the time of establishment. Increases in rust incidence generally occurred when fertilization alleviated a deficiency and resulted in substantial growth improvements. Matziris and Zobel (1976) found increased rust severity on 8-year-old loblolly pine following repeated fertilization with P, potassium (K), and lime on three of four sites in the Lower Coastal Plain. Loblolly and slash pine seedlings growing under controlled greenhouse conditions have exhibited both greater rust incidence and accelerated growth with improved soil fertility (Rowan 1977, Rowan and Steinbeck 1977).

While both loblolly pine and slash pine have shown increased rust incidence following fertilization, this association has been less evident with loblolly pine. Dinus and Schmidtling (1971) found that fertilization increased fusiform rust incidence on slash pine while rust frequency on loblolly pine

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[1/] Paper presented at Southern Silvicultural Rsearch Conference, Atlanta, Georgia, November 67, 1980. Paper No. 6680 of the Journal sries of the North Carolina Agriculture Research Srvice, Raleigh.

[2/] Liaison Forest Soils Specialist, North Crolina State Forest Fertilization Cooperative, Shool of Forest Resources, N.C. State University, Rleigh, N.C. 27650.

growing on the same site was little affected by treatment: both species showed a growth response to fertilization. Site preparation intensity also has a more proncunced effect in increasing rust incidence on slash pine than loblolly pine (Malac and Brightwell 1973).

The research findings cited above show that, to some degree, fertilization of loblolly pine can result in greater rust incidence. These findings, however, are primarily restricted to fertilization at or near the time of planting. What is the impact of fertilizing juvenile loblolly pine stands on subsequent rust incidence? Answering this question was one objective of a regional series of studies established by the North Carolina State Forest Fertilization Cooperative (NCSFFC). Five-year results from this series are the subject of this paper.

METHODS AND PROCEDURES

Forty-one tests were established in 2-9-year-old loblolly pine plantations growing on site prepared land. Study locations ranged from Delaware to Mississippi. Each trial had a randomized complete-block design consisting of a control and four fertilizer treatments replicated four times. The fertilizer treatments tested were selected from eleven different nutrient mixes and varied from study to study. Nitrogen was the principal nutrient examined and was applied at 50 (50N), 100 (100N), and 200 (200N) lbs/acre as ammonium nitrate. Phosphorus was applied at the rate of 50 (50P) lbs/acre in combination with N. Potassium was applied at 50 (50K) lbs/acre in combination with N-P. A mixture of trace elements (TE) was applied in combination with N-P or N-P-K additions. Application rates of TE were as follows: boron-2.4 lbs/acre; cooper-2.4 lbs/acre; iron-14.4 lbs/acre; manganese 6.0 lbs/acre; molybdenum-0.1 lbs/acre.

Height and DBH were determined on all planted loblolly pine trees prior to fertilization and 5 years following fertilizer application. At these same times each tree was catergorized as to the presence to fusiform rust galls according to the following coding scheme:

Code	Tree Characteristic
1	no gall
2	one branch gall
3	two branch galls
4	more than two branch galls
5	one stem gall
6	two stem galls
7	one stem gall & one or more branch gall(s)
8	two stem galls & one or more branch gall(s)
9	lethal stem gall.

Mortality and probable cause of death were noted 5 years following fertilization.

The occurrence of new stem galls, new branch galls, and fusiform rust caused mortality during the 5-year period following study initiation was determined for each tree by comparing the pre-treatment fusiform rust code with the fusiform rust code and mortality information taken 5 years after fertilization. Percent of trees with new stem galls (STEM), percent of trees with new branc galls (BRANCH) and percent of trees dying from fusiform rust (MORTALITY) were then determined for each plot. These measures of infection durin the 5-year period following treatment should be sensitive to any fertilization induced changes in susceptibility of loblolly pine to rust. Statist cal analyses of rust data were performed followin arcsine $\sqrt{x}$ transformation. An analysis of varia for each of the above fusiform rust variables was performed for each fertilizer trial.

Mean 5-year volume/A, basal area/A, diameter and height growth were determined for each treatment in each stand.

Rust and growth data from each study were reviewed to isolate responses to specific fertili elements tested. These responses were calculate as the difference in 5-year rust infection and tree growth between two treatments differing only in the fertilizer element of interest. For examp if in a particular stand STEM was 15% on the 100N treatment and 12% on control plots then STEM response to N would be 3%. Similarly, if in the same stand STEM was 19% on the 100N-50P treatmen then STEM response to P would be 4%.

Data combined from different stands were analyzed to evaluate relationships between rust variables, fertilizer element, growth response, stand age at time of treatment. These relations were evaluated for two data sets; one containi all stands and a second containing 12 "high" rus stands. High rust stands are defined here as th stands where the increase in fusiform rust galls on nonfertilized trees during the 5-year assessm period exceeded 15% for STEM and 10% for BRANCH. These stands were located on areas of South Caro Georgia, and Alabama where fusiform rust incide is commonly high (Squillace 1976). Most of thes stands were located on well drained sites in the Piedmont and Gulf Coastal Plain.

STAND CHARACTERISTICS

Characteristics of the plantations examine are presented in table 1. The majority of the stands had a low percentage of trees developing new rust galls or dying from rust during the 5 years following study establishment. Mean STEM control plots averaged 11.4% overall and 28.8% high rust stands. Mean BRANCH was similar to mean STEM. MORTALITY on control plots averaged 2.5% overall and 5.7% in high rust stands. Bot the overall and high rust data sets contain a s stantial range of ages, mean heights, amounts o rust at the time of fertilization, and 5-year v ume responses to N and P fertilization. Volume res ses to K were also highly variable while growth imp ve- ments were generally not noted with TE additi n. Both K and TE were infrequently tested in high st stands.

Table 1. Summary of pretreatment stand characteristics, 5-year rust infection without fertilization, and 5-year volume response on all stands (n = 39) and high rust stands (n = 12).

	-------All Stands-------			----High Rust Stands----		
Variable	Mean	Std.Dev.	Range	Mean	Std.Dev.	Range
retreatment Stand Characteristics						
Age (yrs)	5.0	1.9	2,9	4.4	1.8	2,9
Mean height (ft)	10.8	4.7	3,20	13.6	3.2	9,20
Trees infected (%)	14.4	16.1	0,63	23.1	17.8	2,57
-year Infection on Controls Plots						
STEM (%)	11.4	13.0	0,51	28.6	10.1	17,51
BRANCH (%)	12.4	13.8	0,61	28.8	14.9	10,61
MORTALITY (%)	2.5	3.4	0,12	5.7	3.4	2,12
year Volume Response						
N (ft^3/A)[1]	92.0	137.0	-195,+392	92.0	15.5	-142,+373
P (ft^3/A)[2]	111.5	96.6	-64,+301	85.3	89.6	-64,+198
K (ft^3/A)[3]	19.8	100.5	-191,+183	182.0	1.4	181,+183
TE (ft^3/A)[4]	-47.4	95.2	-146,+126	-36.5	155	-146,+73

[1] N effect determined in 39 stands; 11 high rust stands.

[2] P effect determined in 30 stands; 8 high rust stands.

[3] K effect determined in 16 stands; 2 high rust stands.

[4] TE effect determined in 11 stands; 2 high rust stands.

RESULTS

Individual Stand Results

Results from analysis of variance of STEM, BRANCH, and MORTALITY for each of the 41 stands are summarized in table 2. Few significant differences among fertilizer treatments were observed in the percent of trees either with new rust galls or dying from rust, even at low levels of probability. Fertilizer treatments were not associated with significant differences (5% level) in STEM in any of the plantations.

Table 2.--Summary of statistical significance of treatment difference in 5-year fusiform rust infection in 41 stands.

	------Significance Level[1]-------			
Rust Variable	<5%	<10%	<25%	>25%
	[no.of stands with fertil. effect]			
STEM	0	0	6	35
BRANCH	2	3	9	32
MORTALITY	1	4	5	36

[1] Probability that treatment differences were a random occurrence rather than a true fertilizer effect.

Significant (5%) differences in BRANCH between fertilizer treatments were observed in only two stands, both of which had low amounts of rust infection during the 5-year period monitored. The nature of the apparent rust response in these two stands differed: BRANCH was increased by N fertilization in one stand but decreased by it in the other. Significant differences in MORTALITY between fertilizer treatments were observed at only one location; MORTALITY was lower in two fertilizer treatments than in the control (3.3%, 0.7% vs 9.5%). No significant treatment differences in STEM or BRANCH were observed in high rust stands.

Combined Stand Results

Effect of Specific Nutrient Elements

Mean responses in 5-year rust infection and ranges of response associated with specific elements are presented in table 3. Mean responses were very small and analysis by paired t tests showed no significant effect. However, there was a considerable range in STEM, BRANCH, and MORTALITY responses associated with the specific elements indicating possible site and stand effects on fusiform response to fertilization.

Table 3. Mean response[1] and range in response in 5-year rust infection associated with N, P, K, and TE additions.

Nutrient	No. of Stands	---Rust Variable--- STEM	BRANCH	MORTALITY
		--(Change in percent infection with nutrient)--		
All Stands				
N	39	-1.2[2] (-11.6,+7.5)[3]	0.6 -6.4,+14.4	-0.2 (-7.5,+5.0)
P	30	0.7 (-13.7,+16.8)	0.1 (-15.2,+9.7)	0.6 (-2.3,+3.7)
K	16	-1.4 (-12.4+3.8)	-0.7 (-7.9,+12.0)	0.2 (-2.0,+3.4)
TE	11	1.6 (-4.3,+11.2)	0.5 (-5.7,+8.5)	-0.6 (-3.0,+1.7)
High Rust Stands				
N	11	-3.0 (-11.6,+7.5)	0.8 (-3.7,+7.0)	-1.4 (-7.5,+5.0)
P	8	1.6 (-7.5,+16.8)	-1.7 (-15.2 +[illegible])	1.0 (-0.7,+3.7)
K	2	-8.6 (-12.4,-4.7)	-4.5 (-7.9,+1.0)	0.3 (-1.2,+1.7)
TE	2	6.9 (2.6,+11.2)	2.0 (-0.4,+4.4)	-1.3 (-1.8,-0.7)

[1] Mean responses were not significant at the 5% level.

[2] Negative values indicate reduced amounts of rust with nutrient application while positive values indicate increased amounts of rust with nutrient applications.

[3] Range of rust responses.

Relationships Between Stand Factors and Rust Response to Specific Elements.

Stand age at the time of treatment, the amount of rust infection occurring without the application of a specific nutrient, and the degree of growth response to fertilization were hypothesized to be the variables most likely to influence the nature and magnitude of any fertilizer induced change in the frequency of subsequent rust infections and mortality. Correlation coefficients (r) between STEM, BRANCH, and MORTALITY response to N, P, K, and TE fertilization and the above variables are given in table 4. Correlation coefficients could not be determined for relationships with rust response to K or TE in high rust stands because of the lack of sufficient observations.

Stand age at the time of fertilization had little apparent influence on the effect of fertilization on subsequent rust infections.

Table 4. Correlation coefficients (r) between rust response to specific nutrients and stand age at fertilization, 5-year rust infection on base treatments,1/ and 5-year volume response.

Variables correlated	All Stands				High Rust Stands	
	N	P	K	TE	N	P
	r					
Age vs.						
STEM Resp	-.15	-.28	-.03	.36	-.09	-.10
BRANCH Resp	.14	.21	-.18	-.46	.07	.62
MORTALITY Resp	-.09	-.18	.10	-.09	-.05	.30
Base TRT Level vs.						
STEM Resp	-.36*	-.22	-.55*	-.25	.15	-.70
BRANCH Resp	-.09	-.45*	-.35	.01	-.11	-.41
MORTALITY Resp	-.44*	-.12	-.33	-.15	.30	-.56
Volume Resp vs.						
STEM Resp	-.13	-.18	-.45	-.64*	-.15	.26
BRANCH Resp	.24	.46*	-.04	-.20	.58	.29
MORTALITY Resp	-.19	-.25	.11	-.39	-.28	.34

* Significant at 5% level.

1/ Base treatments are control for response N, N alone response to P, N-P for response to K and N-P-K for response to TE.

There was generally a negative relationship between rust response to fertilization and the 5-year infection level on the base treatment (control for response, to N, N alone for response to P, N-P for response to K, N-P-K for response to TE). This relationship was significant for STEM and MORTALITY response to N, BRANCH response to P, and STEM response to K. These significant relationships were observed only for the data set containing all stands. The relationship between STEM response to K and STEM on the base treatment (no K) is illustrated in figure 1. Greatest reductions in the amount of trees with new stem galls during the 5 years following K applications occurred in stands experiencing heavier infections during this period.

Volume responses to N and P tended to have a different relationship with BRANCH response than

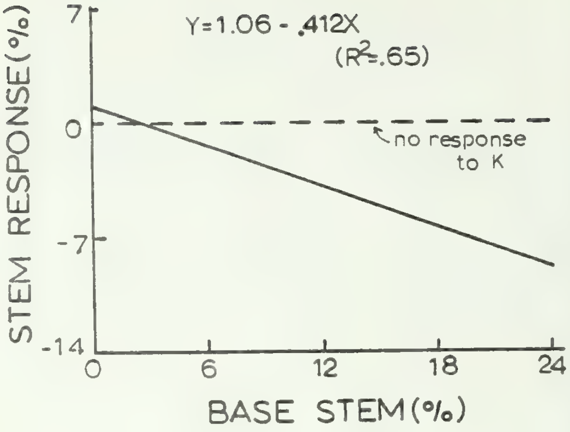


Figure 1.--Relationship between STEM response t K (Y) and STEM on the base treatment (X).

with STEM and MORTALITY response. BRANCH respon to fertilizer elements was positively correlated with growth gains from the same fertilizer eleme while the reverse associateion was generally app ent for STEM and MORTALITY response. The posit correlation between BRANCH response and volume response to P was significant for the overall da set. This relationship is presented in figure BRANCH, relative to that on the base treatment, tended to increase with increasing volume respo to P. Segregation of studies by magnitude of y response (<75 ft^3/A, 75-150 ft^3/A, & > 150 ft^3 also indicated this relationship between growt response and the amount of rust; the percentage trees with new branch gall was significantly re- duced with P additions on low responsive sites a significant increase in this measure of infec was noted in stands responding strongly to P fe ization. However, the mean increase in the amo of trees with new branch galls on strongly resp ing sites was relatively small, averaging only

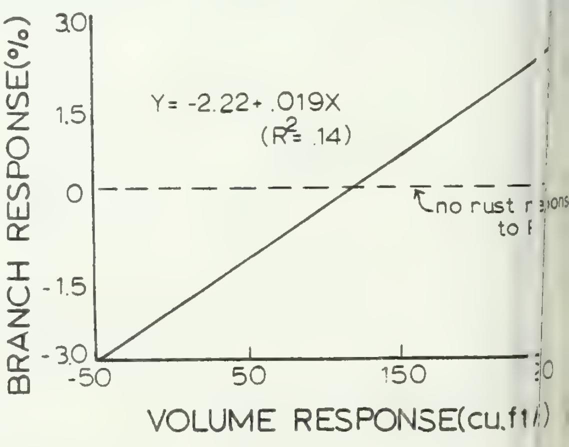


Figure 2.--Relationship between BRANCH respons P(Y) and volume response to P (X).

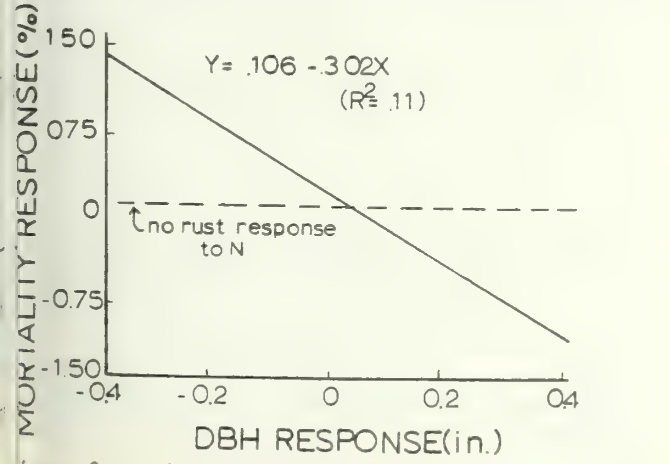
In contrast to BRANCH response, STEM and ORTALITY response to N and P fertilization was ower on sites showing a greater volume response to hese elements, but these relationships were not ignificant. However, MORTALITY response to N was ignificantly correlated with basal area response $r = -.32$), height response ($r = -.34$), and diameter esponse ($r = -.37$) to N. The relationship between esponse to N in DBH growth and MORTALITY is resented in figure 3. Nitrogen fertilization can ither increase or decrease the amount of trees ying primarily from rust. The amount of mortality ttributed to rust tended to increase in stands here N fertilization resulted in growth reductions. onversely, rust mortality tended to be reduced when fertilization improved the rate of growth.

Relatively strong negative correlations were bserved between volume response and STEM response o K and TE. The significant relationship between esponse to TE in volume and STEM is illustrated n figure 4. Increases in the percent of trees eveloping new stem galls generally occurred when E additions suppressed pine growth.

ive-Year Rust Infection in Stands Strongly Responding to N and P.

Stands most likely to be fertilized are those xpected to show the greatest gains in growth. TEM, BRANCH, and MORTALITY in stands responding trongly to N (> $150\ ft^3/A$) are depicted in figure . Differences in STEM and BRANCH associated with fertilization were not significant and relatively mall, even for stands with large increases in rust. he largest difference between treatments was ssociated with reduced MORTALITY with N in high ust stands.

Five-year rust infection on plots receiving ontrol, N, and N-P treatments in stands showing substantial volume response to P (> $150\ ft^3/A$) s illustrated in figure 6. The previously iscussed significant increase in BRANCH with dditions to these stands is evident. Differences n STEM and MORTALITY on the N and N-P treatments ere not significant. Differences in STEM reflect nusual disease levels with N alone on the two high ust stands examined. Both of these stands xhibited moderate growth improvements with N alone.



igure 3.--Relationship between MORTALITY response to N (Y) and response in diameter growth to N (X).

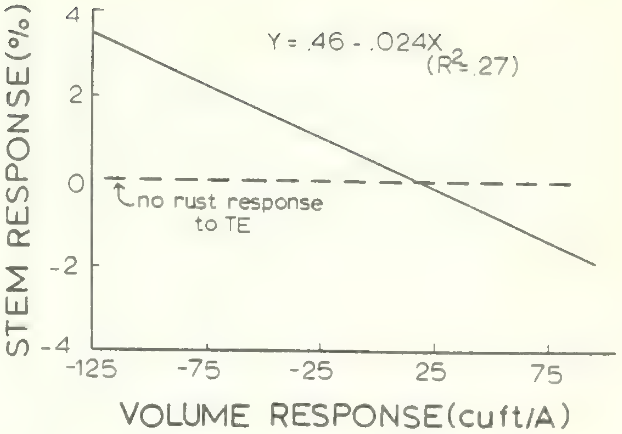


Figure 4.--Relationship between STEM response to TE (Y) and volume response to TE (X).

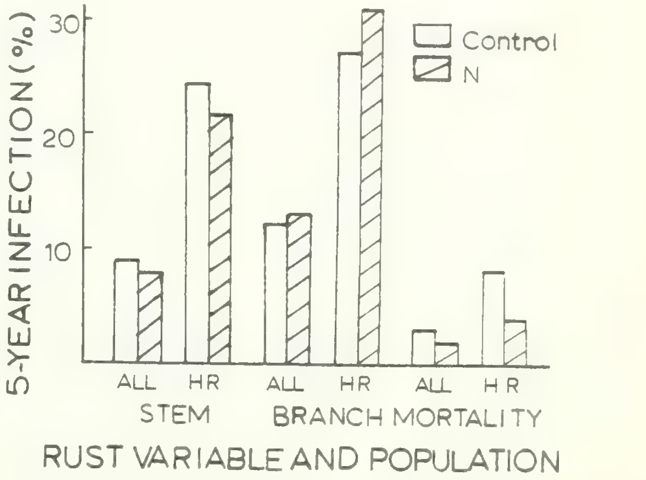


Figure 5.--Mean rust infection and mortality during the 5 years following fertilization in all stands responding strongly to N (n = 11) and in strongly responding high rust (H.R.) stands (n = 3).

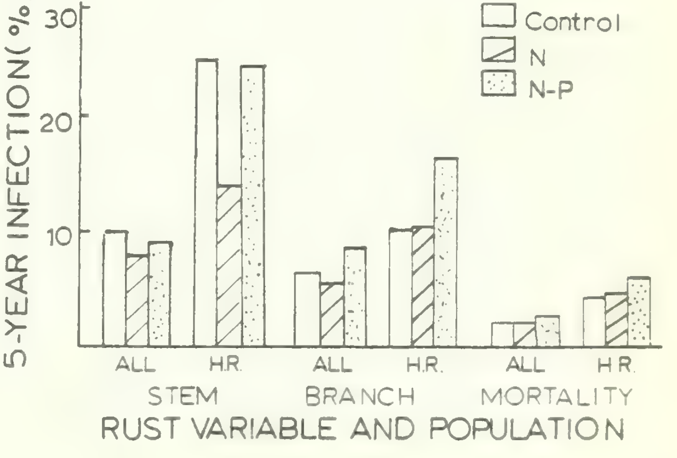


Figure 6.--Mean rust infection and mortality during the 5 years following fertilization in all stands responding strongly to P (n = 10) and in strongly responding high rust (H.R.) stands (n = 2).

DISCUSSION

The results of this study show that fertilization of 2-9-year-old loblolly pine stands generally had little impact on subsequent fusiform rust incidence. The amount of new galls and mortality caused by rust during the 5-year period following fertilization was generally about the same on fertilized and nonfertilized control plots. The specific nutrients evaluated were not associated with consistent or substantial changes in the percent of trees with new galls or the percent of trees dying from rust over all sites.

There were notable trends within the narrow ranges observed in rust response. Where fertilization with P increased the rate of tree growth it also tended to induce an increase in the percent of trees with new branch galls. However the increase in the amount of rust was inconsequential. The second relationship of note was that between tree response to N and the amount of rust related mortality. The apparent reduced mortality on sites responding strongly to N suggests that improved tree vigor has enhanced the ability of trees to survive potentially lethal stem infections. This aspect of the fertilizer-rust relationship requires further study. Finally, there was a general tendency for fertilization, particularly with K, to reduce the amount of subsequent rust infection in stands experiencing relatively high rates of infection.

The 41 stands examined represent a substantial range in stand age at time of fertilization, rust infection during the period monitored, and growth response to fertilization. Many of the stands had low rust infection levels during the 5 years after study initiation. These stands were either 1) located in areas of low rust hazard or 2) located in areas of high rust hazard in stands where the major infection period had preceded fertilization. The results described above support the contention that similar stands can be fertilized without fear of increased rust incidence. More importantly, these results show that fertilization generally did not increase susceptibility to fusiform rust of juvenile loblolly pine stands which experience substantial subsequent infection. The stands with high rates of infection during the 5 year period evaluated were principally on better drained sites in the Piedmont and Gulf Coastal Plain. Growth responses were common in these stands but severe deficiencies were not encountered. It is not known if fertilization of established plantations on severely deficient sites in areas of high rust hazard will result in increases in rust incidence as well as substantial growth gains.

CONCLUSIONS

Fertilization of juvenile loblolly pine stands growing on most sites in the Southeast will not significantly alter the subsequent incidence of fusiform rust. This lack of substantive effect has been demonstrated for a variety of combinations of stand age at treatment, infection level on nonfertilized plots during the period evaluated, and the magnitude of growth response to fertilization. While large consistent changes in fusiform rust incidence following fertilization were not observed, results have shown that fertilization can increase or decrease subsequent rust severity. The proportion of trees developing new branch gall was increased when P resulted in strong growth responses. On the other hand, fertilization generally tended to reduce the amount of subsequen infection and mortality in stands with relatively high rates of infection and mortality during the period evaluated. Rust related mortality also tended to be reduced when N fertilization stimulat growth. These findings apply to many stands in th Southeast but do not directly apply to fertilizati of stands on severely nutrient deficient sites in high rust areas; such stands were not evaluated i this study.

LITERATURE CITED

Bengtson, G.W. 1979. Forest fertilization in th United States: Progress and outlook. Journal For. 77:222-229.

Dinus, R.J. and R.S. Schmidtling. 1971. Fusifor rust in loblolly and slash pine after cultivati and fertilization. USDA Forest Serv. Res. Pa SO-68, 10 p.

Hollis, C.A., W.H. Smith, R.A. Schmidt, and W.L. Pritchett. 1975. Soil and tissue nutrient, soil drainage, fertilization, and tree growt as related to fusiform rust incidence in sla pine. Forest Sci. 21:141-148.

Malac, B.F. and C.S. Brightwell. 1973. Effect site preparation on growth of planted southern Union Camp Woodlands Res. Note 29. 9. p.

Matziris, D.I. and B.J. Zobel. 1976. Effect of fertilization on growth and quality characteri tics of loblolly pine. Forest Ecol. and Man 1: 21-30.

NCSFFC. 1980. An inventory of forest fertiliza trials in the Southeast. School of Forest Resources, N.C. State Univ., NCSFFC Report No. 2, 23 p. (unpubl.)

Rowan, S.J. 1977. Fertilizer-induced changes susceptibility to fusiform rust vary among families of slash and loblolly pine. Phytopathology 67: 1280-1284.

Rowan, S.J. and K. Steinbeck. 1977. Seedling and fertilization affect susceptibility of lo lolly pine to fusiform rust. Phytopatholog 67: 242-246.

Squillace, A.E., 1976. Geographic patterns of fusiform rust infection in loblolly and slash plantations. USDA For. Serv. Res.Note SE-2 4 p.

USE OF LEGUMES IN SOUTHEASTERN FORESTRY RESEARCH[1]

Jacques R. Jorgensen[2]

Abstract.--Legumes have been established on a wide range of sites in the Southeast to determine their adaptability, fertility requirements, and influence on the site and on the growth of recently planted trees. The majority of legumes are not suitable for forest planting. The winter annual subterranean clovers and the summer annual and perennial lespedezas are the legumes best adapted to the competition, low degree of site preparation, and adverse soil conditions of the typical forest planting. Legumes have responded to P fertilization, with source of P important on some sites. Legumes increased site N and increased the N content of loblolly pine foliage.

INTRODUCTION

Nitrogen (N) is essential for all living rganisms. Forest trees respond to this element ore frequently than to any other fertilizer utrient. However, response to N or to any eleent is limited by deficiencies of other nutrients nd other factors such as moisture and sunlight. here is a trend—an economic necessity—toward upplemental forest fertilization for sites where rowth potential is limited by those factors that an be economically manipulated. The economic enefits of forest fertilization were realized in he 1960's and early 1970's when chemical fertiizers were inexpensive relative to their beneits. In the mid-1970's, however, the glut of ow-priced N fertilizer came to an end for a umber of reasons, primarily because of the direct elationship between chemically transforming atospheric N into a form usable by plants and the ost of energy.

The increasing cost and potential restriction n the use of energy for the production of fertiizer has renewed interest in another N source, iologically fixed N, one that has been known but not understood since the development of plant cultivation in ancient civilizations. The initial attempts to integrate the use of legumes into forestry began in central Europe in the first half of the twentieth century where lupines were used experimentally to aid in the rejuvenation of degraded forest soils. More recently, interest in biological N fixation has spread to Australia and New Zealand where it has been used to aid soil stabilization and to improve soil fertility in general. Until recent years, in the United States, biological N fixation in forestry has usually been practiced through the use of nurse crops such as black locust or various alders that would later be removed when the more desirable species were established. The majority of the early plantings with these species were not markedly successful due to poor site conditions and improper selection of the nurse crops which often outgrew the species desired for the final stand.

WORK AT THE SOUTHEASTERN FOREST EXPERIMENT STATION

In 1973, limited work was begun to determine if N-fixing plants could contribute to the N economy of a site and eventually to the growth of planted pines and hardwoods. Both exotic and native N-fixing plants were used in a series of field tests in which most of the candidate plants failed to become established. In 1975, a screening program was introduced to select species that could adapt to the severe conditions often found in the forest situation. Initially, we established four primary criteria and several secondary criteria for use in the selection of N-fixing plants. The primary criteria were:

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Fix nitrogen--Candidate plants should be able to fix significant quantities of nitrogen, with 50 to 100 kg of N/ha taken as the minimum annual rate. This rate of fixation should be maintained for 3 to 5 years to provide an economic return.

Tolerate infertile, acid soils--Plants should be able to grow in soils fertilized primarily to benefit tree growth. In most instances, this would exclude lime and potassium additions to the soil where pines are to be grown.

Be easy to establish--Seed should germinate quickly and seedlings be sufficiently vigorous to establish themselves in spite of poor soil conditions and weed competition.

Be self-maintaining--Plants need to be perennials or reseeding annuals capable of establishing dense vigorous stands. However, a balance must be established between the vigor of the N-fixing plant and the final crop tree. No more kudzus!

Secondary criteria included:

Shade tolerance--The greater the shade tolerance, the longer the period of N fixation.

Growth that occurs primarily in the fall, winter, and early spring--Growth during the cool season reduces the competition between the trees and N-fixing crop for moisture and nutrients. This is especially important in hardwood plantations.

Weed control--When cover crops are used in hardwood plantations, weed control is an especially useful feature. A dense stand of plants or plant residues in late spring or early summer inhibits weed growth, which reduces competition and the need for cultivation. A cover of plants on the soil surface throughout the year will also reduce erosion.

Benefit (or unharmful) to wildlife--Some N-fixing plants are of no direct benefit to wildlife and may even be poisonous. However, many species have both the ability to fix N and produce valuable seed and forage for wildlife.

Lack of interference with forest management--Trailing climbing vines, flammable waxy leaves, spinney leaves and branches, and shrubs that form impenetrable thickets are all characteristics unfavorable to forest management. Wax myrtle, kudzu, some lespedezas, and European gorse each have some of these undesirable features.

The ideal plant for forest sites would be a herbaceous, fast-growing winter perennial with a low profile that is esthetically attractive. It should be able to grow and compete with weeds with little site preparation or fertilizer, fix copious amounts of N, and provide seed, forage, and cover for wildlife over a period of several years. We attempted to identify this ideal plant through screening, first by reviewing the literature and then by using the more promising candidates in field trials. In the field trials, we tested three factors: 1) the plant itself, 2) th relationship of plant growth to soil fertility, and 3) the relationship between the legume and tree growth and the factors that influence this growth.

Plant Selection

Although there are about 18,000 species of legumes, of which about 200 are found in the Southeast, we have confined our work to those which are agronomically important. The reasons include both knowledge of the plant and seed availability. Much is known about the managemen of agronomic legumes for maximum growth and abou their N-fixing capabilities. Except in a very general way, relatively little is known of the growth requirements or the N-fixing capabilities of the wild legumes, but they do offer a fertile field for investigation. Seed availability also plays an important part in N-fixing plant selection. Commercially produced seed available at low prices eliminates one step that would be necessary if a wild legume had been selected. There are instances where plants have desirable characteristics—dwarf lespedezas and desmodium are examples—but seed production is so limited that they are essentially eliminated from large-scale planting trials.

Over 70 species and varieties of N-fixing plants have been field tested to determine thei suitability for use in forestry (table 1). The majority of these plants have been agronomically important legumes and, as expected, most of the plants are not adapted to forest conditions. (the plants examined, only about a dozen are st actively under consideration, although additio species and varieties are tested annually.

Table 1.--Results of species and varietal trials 1976-79

Plant group	No. of species and varieties examined	Results	
		Testing discontinued	Testing continue
Lupine	14	14	0
Clover	24	19	5
Vetch	4	4	0
Lespedeza	9	2	7
Other	20	1/	1/

1/ Testing of several species continues but is often limited availability of seed.

Testing consists of growing the plants u er one or more soil and fertilizer regimes. The number of trials, which total over 200, range from over 20 devoted to 'Mt. Barker' subterra n clover to one trial with mung beans. The num f trials are directly related to the potential f the plant. The primary reasons for failures re: 1) the plants are not adapted to harsh site onditions, 2) disease, and 3) failure of annuals o regenerate.

One of the most common problems in establish- ent is with small seed which produce tiny plants hat are insufficiently vigorous to adapt them- elves to adverse conditions. In some instances, s with lupines, the testing site was unsuitable nd poor growth, accompanied by root rots and leaf iseases, eliminated most of the plants before aturity. Vetch stands were usually not dense nough to compete with weeds and, within a few ears, the legume was eliminated. Browsing causes evere problems in the establishment and growth f many species.

Two groups of plants—clovers and lespedezas— ave produced the majority of potentially useful lants. Within these two groups, the following pecies or varieties are promising:

ubterranean Clover—'Mt. Barker' and 'Tallarook' arieties

'Mt. Barker' and 'Tallarook' subterranean lovers are midseason and later winter annuals in hich most growth is completed by late May. Good tands of these plants will contain over 200 kg f N/ha, the majority of which will have been ixed biologically. Subterranean clovers are olerant of acid, low-fertility soils in which ost other clovers fail to grow. They are othered by few diseases and insect pests. The rop has a spreading, low profile that is some- hat resistant to browsing. A low, dense mat of lant remains persists through much of the summer nd can exert a high degree of weed control. hese varieties are prolific seeders. The ajority of seeds are produced in burrs which bury hemselves in the soil. Seed are desirable food or birds and other wildlife.

rrowleaf Clover—'Yuchii' and 'Meechee' Varieties

These are tall, winter annuals in which rowth may continue through June. Dense stands f these plants can be obtained from initial eedings. In many instances, successful volunteer tands have failed due to poor seed set, distri- ution, or other factors. Arrowleaf clovers ppear more sensitive to site conditions, and ore subject to disease than the subclovers.

ose Clover

A low-profile, upright clover that has per- isted and formed dense stands in one study. The lant appears tolerant of acid, low-fertility oil, and needs to be further tested.

Sericea Lespedeza

This herbaceous summer-growing perennial is easy to establish, tolerant of adverse soil conditions, and not affected by disease and insects. It has been used agriculturally for soil improvement and can fix considerable quantities of N. Sericea is somewhat shade tolerant and produces hard seed which persist for many years in the forest floor. The forage and seed of common sericea are of limited value to wildlife because of their high tannin content, although varieties have been developed which are lower in tannin. If not properly managed, sericea can compete vigorously with planted trees.

Virgata Lespedeza—'Ambro' Variety

This low-growing, perennial lespedeza, recently released by the Soil Conservation Service, is less aggressive than sericea. Stand establishment may be limited by slow-growing seedlings during the first year.

Thunbergii Lespedeza—'VA-70' Variety

A tall-growing wood shrub that is easy to establish and is tolerant of adverse soil conditions. Seed are valuable for wildlife, but forage is not extensively browsed. N-fixing capacity is about equal to that of sericea.

Fertilization

There are three factors to be considered when legumes and other N-fixing plants are fertilized: 1) legume growth desired, 2) nutrient recycling, and 3) the nutrient needs of the trees.

Small quantities of fertilizer applied to forest-grown legumes may be sufficient for sustained crops, whereas the same quantity of fertilizer on the agronomic crop may result in stand failure. In agronomy, forage is removed by grazing or by hay production. This forage contains a portion of the fertilizer applied to the site to increase production. In forestry, except through wildlife consumption and losses through leaching, fertilizer elements taken up by the legumes remain on the site and, provided that they are in an available form, can be reused without limit. This is the same nutrient cycling principle that enables continued harvest and growth of forest stands so long as the harvest does not exceed normal nutrient inputs to the site.

Since trees are the primary crop and legumes the secondary, the major fertilizer application to the legume should also benefit the trees. Pines have little or no positive response to lime or to potassium (K), so only under special circumstances, where other than simple N accretion is desired, would large applications of these elements be justified. Fortunately, trees often respond to phosphorus (P), and we have found that the application of this element is essential for the growth and development of most legume stands. In greenhouse trials, three varieties of clover, hairy vetch, and Austrian winter pea were grown on Coxville sandy clay loam, a clayey, poorly drained, high organic matter soil, and also on Appling loamy sand (Jorgensen 1978).[3/] On these soils, legumes failed to grow when no fertilizer was applied but grew equally well with ground rock phosphate (GRP) alone or with P + K + lime applications. Plants grown on Wickham loamy sand, a soil relatively high in available P and with a pH of 5.5, produced a crop without the addition of fertilizer but the addition of P alone or P + K + lime significantly increased yield. Two nonagronomic legumes, false anil indigo and partridge pea, grown on the same three soils showed much less response to the fertilizers than did the agronomic legumes. Neither species responded to fertilizers on the Wickham soil. Partridge pea responded to fertilizer on the Coxville and Appling soils, but also produced acceptable yields without the fertilizer additions.

Field installations of legumes have produced results similar to those obtained in greenhouse trials. The essential fertilizer ingredient has been P. Stands of annual legumes have usually failed the first year without a P application. When perennial plants are grown without a P application, the initial stand is gradually eliminated by the more competitive weeds.

The rate of P application in most studies has been about 112 kg/ha. This amount is usually sufficient for the study period which lasted 4 years in one instance. In other studies where P was the variable, there was no difference in legume growth on well-drained soils when from 56 to 280 kg/ha of P were applied.

Phosphorus applied as GRP has generally elicited a better legume response than it has as triple superphosphate (TSP), especially where some drainage problems exist. The better response with GRP may be the result of its greater calcium content or due to the availability of the P over a long period of time. In a recent study in the South Carolina Coastal Plain, growth of subterranean clover was better with GRP than with TSP but the addition of 4,480 kg of lime/ha with the TSP was better than the GRP alone.[4/] Growth of the subterranean clover with GRP alone would have been satisfactory in a pine plantation where weed control was not absolutely necessary and liming would not have benefited the trees. In this particular instance, the experimental treatment was adjusted to that of a hardwood plantation in which the lime application was desirable and weed control was necessary.

Measurements to determine the influence of P on legume biomass production and N fixation are being carried out in a loblolly pine plantation planted with sericea lespedeza (tables 2, 3). The addition of P without legume had no appreciabl influence on either the amount of nonwoody biomass (weeds) produced or the N it contained. Annual biomass production on control and P only plots over a 3-year period averaged 5.2 t of weeds/ha which contained 40 kg of N/ha. Sericea sown without P produced little biomass, and production nearly ceased by the fourth year.

Table 2.--Influence of fertilization and legumes on nonwoody biomass productior

Treatment	Years since establishment	Biomass			
		Surface litter	Weed	Legume	Tota
		t/ha			
Control	2	0	3.8	0	3.8
	4	0	5.6	0	5.6
Phosphorus[1/]	2	0	4.1	0	4.1
	4	0	7.1	0	7.1
Sericea	2	0	2.3	.3	2.6
	4	0	4.5	.1	4.5
Sericea + P[1/]	2	0	.8	6.6	7.4
	4	15.6	.7	9.0	25.3

[1/] 89 kg/ha of P applied as ground rock phosphate.

Table 3.--Influence of fertilization and legumes on nitrogen in soil and in nonwoody biomass

Treatment	Years since establishment	Soil depth (cm)			Biomass				
		0-10	10-20	0-20	Surface litter	Weed	Legume	Total biomass	Soil & bioma
		kg N/ha							
Control	2	944	536	1,488	0	25	0	25	1,513
	4	1,201	771	1,972	0	47	0	47	2,019
Phosphorus[1/]	2	902	428	1,330	0	27	0	27	1,357
	4	1,282	658	1,940	0	61	0	61	2,001
Sericea	2	926	504	1,430	0	18	4	22	1,452
	4	1,061	672	1,733	0	38	1	39	1,772
Sericea + P[1/]	2	1,100	545	1,645	0	8	121	129	1,774
	4	1,372	698	2,070	183	10	127	320	2,390

[1/] 89 kg/ha of P applied as ground rock phosphate.

The addition of P to sericea plots resulte in an increase of over 400 kg of N/ha in the system by the fourth year, compared to plots without this combination. Most of the N increas was related to the living legume biomass and litter. Total biomass on the sericea + P plots amounted to 25 t/ha, nearly five times that of control plots. The amount of N in biomass was about the same the third and fourth years, but the distribution changed. The largest portion was in the living biomass during the third year but in litter by the end of the fourth year.

[3/] Jorgensen, J. R. 1978. Growth of legumes on forest soils fertilized at low rates. USDA For. Serv., Res. Note SE-251, 7 p. Southeast. For. Exp. Stn., Asheville, N.C.

[4/] Personal communication, D. Gerwig, Westvaco, Summerville, S.C.

Sampling variability made it difficult to termine if there had been any increase in soil The top 20 cm of soil from plots with sericea P contained 98 kg more of N than did the control ot, but this was not significant at the 5 rcent level. Neither were there significant fferences between the two treatments for soil yers of 0 to 10 and 10 to 20 cm.

Nitrogen fixation on plots with sericea + P curred; however, the amount of fixation cannot accurately determined due to large sampling riation for both nonwoody biomass and soil d also because of the unknown quantity of N ken up by the woody biomass—primarily loblolly ne—on the site. It appears, though, that rough the fourth year a well-established sericea and can add about 100 kg of N/ha/year to a te. But there are still questions about the ilization of this N.

fect of Legumes on Tree Growth and Nutrient take

Trees initially respond to N fixed by legumes increasing foliar N. Foliage of sweetgum seedngs on winter annual legume plots had greater N ntent when sampled a few months after the death the legumes than did foliage of control seedngs (table 4). Sweetgum grown with no N fertilzers, legumes, or cultivation had N concentraons of 1.53 percent in green leaves and 0.92 rcent in red leaves. However, when subterraan and arrowleaf clovers were grown with the cultivated sweetgum, the N content of their een leaves averaged 2.12 percent and red leaves eraged 1.64 percent. Operational fertilization, which 50.4 kg/ha of P and 44.7 kg/ha of N as ammonium phosphate was placed in the planting it and the trees cultivated, produced green aves with N concentrations of 2.3 percent and red leaves. This suggests that even though gumes contribute to the N economy, the supply nerated during one growing is insufficient for timum growth and the elimination of red leaves. w K content of the red leaves was related to eir low N content. Phosphorus, calcium, and magnesium contents of leaves were unrelated to leaf color or N concentration.

T e 4.--Nutrient concentration in green and red sweetgum leaves of 1-year-old plants following one rotation of winter annual clover

tment	N		P		K		Ca		Mg	
	G1/	R1/	G	R	G	R	G	R	G	R
	-----	-----	-----	-----	Percent	-----	-----	-----	-----	-----
+ lime2/	1.53	0.92	0.19	0.14	0.43	0.22	0.52	0.59	0.52	0.50
lover + [illegible] + lime2/	[illegible]	1.32	.23	.19	.35	.23	.52	.60	.47	.47
wleaf clover + K + lime2/	[illegible]	[illegible]	[illegible]	[illegible]	.44	.36	.46	[illegible]	.41	[illegible]
ational atment3/	2.30	-	.18	--	.41	--	.23	-	[illegible]	--

1/ G = Green leaves, R = Red leaves.

2/ 56 kg/ha of P as triple superphosphate + 56 kg/ha of K as potassium chloride + 2,240 kg/ha of lime, no cultivation.

3/ 50.4 kg/ha of P and 44.7 kg/ha of N as diammonium phosphate in planting slit and cultivation.

Over a 4-year period, perennial lespedezas have had a positive influence on the nutrient content of loblolly pine foliage (table 5). These trees, planted on a site 90 soil, responded to a sericea-P fertilization combination by increasing foliar N about 10 percent over that found in controls (1.52 vs. 1.37) at the end of the fifth year. The N concentration of controls was higher than 1.2-percent value taken as the limit above which a large response to N fertilization is not expected. This upper limit was exceeded each year measurements were made, regardless of treatment. Phosphorus did not behave like N; in control plots it gradually decreased from 0.11 percent in the foliage of 3-year-old trees to 0.07 percent 2 years later. The latter concentration is below the 0.09 percent deficiency level at which trees would be expected to respond to P applications, all other elements being sufficient. Calcium and K levels in needles were not influenced by legume treatment.

Table 5.--Nutrient concentration in loblolly pine needles, by tree age1/ and cultural treatment

Treatment	Age 3				Age 4				Age 5			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
	-----	-----	-----	-----	-----	Percent	-----	-----	-----	-----	-----	-----
Control	1.30	0.11	0.52	0.16	1.43	0.10	0.55	0.22	1.39	0.07	0.46	0.20
P2/	1.38	.13	.51	.17	1.47	.12	.52	.22	1.34	.11	.48	.22
Sericea	1.36	.11	.54	.17	1.46	.10	.53	.20	1.39	.07	.48	.18
Sericea + P2/	1.46	.14	.56	.19	1.52	.12	.55	.23	1.57	.11	.53	.19

1/ Growing seasons since plantation establishment.

2/ 89 kg/ha of P as ground rock phosphate.

Unfortunately, the site chosen to study the growth response of loblolly pine to lespedeza and P was not sufficiently deficient to produce an immediate treatment effect (table 6). For the first 3 years, the application of P or growing sericea had no influence on the diameter or height of trees. During the fifth year, trees which had a P application with sericea grew significantly more than the trees on the control plots and plots with sericea only. Where only P was applied, diameter and height growth were intermediate—not being significantly different from either the slower growing controls and sericea only treatments or the faster growing trees in sericea + P plots. At no time did the dense stands of sericea have a negative influence on tree growth.

Since the tree's growth response to fertilizer is related to the nutrient content of its needles, no P response is expected when the P content of the needles exceeds 0.09 percent. This concentration occurred through age 4 in loblolly pine. In the fifth year, when P content of the needles dropped to 0.07 percent on unfertilized plots, P became a growth-limiting element and additional growth could be expected. The additional growth was obtained from only one treatment—that in which

Table 6.--Height and diameter of loblolly pine by tree, age1/ and cultural treatment

Treatment	Height at age1/				Diameter2/ at age		
	2	3	4	53/	3	4	5
Control	1.01	1.95	2.80	3.94a	3.8	5.5	6.7a
Phosphorus4/	1.06	2.00	2.84	4.17ab	3.5	5.6	7.1ab
Sericea	.98	1.91	2.82	3.98a	3.8	5.2	6.8a
Sericea + P4/	1.00	1.95	2.90	4.26b	3.9	5.4	7.2b

1/ Growing seasons since plantation establishment.
2/ Diameter measured 15 cm aboveground at ages 3 and 4. Diameter at breast height at age 5.
3/ Means followed by the same letters do not differ significantly at the 5 percent level.
4/ 89 kg/ha of P as ground rock phosphate.

P fertilizer maintained foliar P above the deficiency level and foliar N was elevated by the dense stand of sericea. It is hoped that the response of loblolly pine to the sericea-P combination will continue through the early years of stand closure and a positive economic benefit will be derived.

OTHER AREAS OF INVESTIGATION

Most forage plantings will be made on soils that are relatively inhospitable to legumes. In agronomic plantings, factors such as low pH, low fertility, and low soil moisture can be controlled to some extent to produce an environment favorable not only to the legume, but also to the rhizobial symbiont. In forest plantings, these factors are largely uncontrolled, negatively influencing the rhizobial symbiont, and resulting in poor nodulation and legume stand failure for the lack of N fixation. Since it is impractical to control the soil environment, an alternative is to select rhizobia that can survive adverse soil conditions, infect the emerging legume plant, and efficiently fix large amounts of N. The selection of microorganism strain with these capacities has only recently begun in forest-oriented research.[5/] Progress has been made and will continue as long as there is an interest in the use of legumes to supplement or supplant N fertilizers in the forest.

Recent agronomic investigations have reported improved legume growth and N fixation when plants were inoculated with certain strains of mycorrhizae in addition to the rhizobial symbiont. So far as is known, no investigations involving mycorrhizae and forest-oriented legume plantings are being carried out. This is a desirable field for investigation since the mycorrhizae can aid the higher plant in nutrient gathering, an important consideration on infertile forest soils.

At the present time, legumes are being established experimentally on well-prepared disked seedbeds. Disking serves three purposes: 1) controls competition, 2) mixes fertilizer with the soil, and 3) prepares a seedbed. Seedbed preparation is especially important for providing good contact between the seed and the mineral soil, which improves moisture uptake and, of equal importance, protects the rhizobium inoculum that has been applied to the legume seed. In most instances few rhizobia would survive if seed were sowed on unprepared soil surfaces and exposed to the elements. To avoid expensive site preparation yet retain high populations of rhizobia surrounding the seed, the seed could be coated with a material that would protect the rhizobium until conditions are favorable for seed germination. Coatings have also been reported to increase seed germination and improve survival and early growth of seedlings. Studies on the use of coated seed and minimum site preparation will be undertaken in the near future.

A number of other topics need investigation to improve the reliability of biologic N fixation and its economic attractiveness. These include the investigation of nutritional factors (minor elements), browsing and other use of plants by animals, utilization of legumes for weed control in hardwood plantations, the effects of disease and parasitic plants on N-fixing plants, esthetic of plantation establishment, nutrition conservati and cycling efficiency (especially on sandy sites erosion control, effect of and control of competition promoted by N fixation, and the influence of planting date on legume establishment and yield. The list of topics can continue ad infinitum.

CONCLUSIONS

A small beginning has been made that shows legumes can be established without excessive preparation of forest sites. Legumes on forest sites can fix considerable quantities of N, some of which is readily taken up by the trees and reflected in the N content of their leaves. In one instance, N fixation has been associated wit increased height and diameter of loblolly pine. However, much more work needs to be done before N-fixing plants can be recommended as an alternative to N fertilization as a routine management practice.

Conversion factors: metric to English

Multiply	By	To obtain
kg	2.20	Pounds
ha	2.47	Acres
cm	0.394	Inches
m	3.28	Feet
t (metric ton)	1.102	Pounds

[5/] Personal communication, C. B. Davey, School of Forestry, N.C. State University, Raleigh, N.C.

Scientific Names of Plants Used in Text

ommon Name	Scientific Name
r	Alnus spp.
, mung	Vigna radiata (L) Wilczek var. radiata
er	Trifolium spp.
er, arrowleaf	Trifoloum vesiculosum Savi
er, rose	Trifolium hirtum All.
er, subterranean	Trifolium subterraneum L.
odium	Desmodium spp.
e, European	Ulex europaeus L.
go, false anil	Indigofera pseudotinctoria Matsun.
u	Pueraria lobata (Willd.) Ohwi
edeza	Lespedeza spp.
edeza, sericea	Lespedeza cuneata (Dum.) G. Don
edeza, thunbergii	Lespedeza thunbergii (DC.) Nakai
edeza, virgata	Lespedeza virgata DC.
st, black	Robinia pseudoacacia L.
ne	Lupinus spp.
le, wax	Myrica cerifera L.
Austrian winter	Pisum sativum var. arvense (L.) Poir.
partridge	Cassia fasciculata Michx.
, loblolly	Pinus taeda L.
tgum	Liquidambar styraciflua L.
h	Vicia spp.
n, hairy	Vicia villosa Roth

CAN FERTILIZATION OF LOBLOLLY PINE ON WET SITES REDUCE THE NEED FOR DRAINAGE [1]

O. Gordon Langdon and William H. McKee, Jr. [2]

Abstract.--Available evidence suggests a working hypothesis that fertilization of certain wet sites deficient in phosphorus, calcium, nitrogen, and/or other nutrients can reduce the need for drainage to improve the growth of loblolly and slash pines. The evidence is strong enough for landowners to pilot-test the concept at a relatively low cost on wet sites which appear to have nutrient deficiencies.

Additional Keywords: Slash pine, bedding, soil-site, limiting factors, site productivity, nutrients, soils moisture, soil chemistry, waterlogging, *Pinus taeda*, *P. elliottii*.

Loblolly pine (*Pinus taeda* L.) thrives on many very wet sites but does poorly on others of similar wetness such as wet flats or savannahs. What makes one site excellent for growth and the other very poor? Why do drainage and bedding dramatically increase growth on certain wet sites and not on others? These questions illustrate the dilemma that many foresters face as they put the results of research on drainage, bedding, and soil-site classification into practice.

A common assumption has been that excess moisture is the factor most limiting to growth on very wet sites, but recent work (Ralston 1965, Terry and Hughes 1975, McKee 1977, and Langdon and Hatchell 1977) shows that, at least in some instances, nutrients or other factors may be more limiting than excess moisture. These findings prompted the very practical question posed by our title: "Can fertilization of loblolly pine on wet sites reduce the need for drainage?" If fertilization could be substituted for drainage on identifiable sites, it would be a very attractive alternative because drainage costs are apt to be 3 or 4 times fertilization costs.

Our paper presents affirmative evidence from the literature on the question of substituting fertilization for drainage. It also proposes a working hypothesis on the relationships of site productivity to moisture and nutrients. Our evidence is derived from silvicultural studies that show effects of drainage, bedding, and fertilization on tree growth; from soil-site work that shows the relationships of soil properties to tree growth; and from basic studies of soil chemistry and tree nutrition that reveal some of the interacting effects of soil waterlogging and tree physiology on tree growth. Both practical and theoretical implications of the hypothesis are examined. Our review which follows is intended to give the reader the background and basis for our conclusions.

DRAINAGE IMPROVES GROWTH

Draining very wet sites such as bays and pocosins of the Atlantic Coastal Plan has dramatically increased growth of loblolly pine. On the Hofmann Experimental Forest in eastern North Caro line on a Portsmouth soil, Pruitt (1947), Miller and Maki (1957), and Maki (1955, 1968, 1971) showed that drainage greatly increased the yield of loblolly pine. Yields on drained plots (2600 cu. ft./ac.) at age 17 were 13 times greater than those on undrained plots (199 cu. ft./ac.). In a similar study in North Carolina, Terry and Hughes (1975) demonstrated comparable responses on a Bayboro-Bladen soil association: At age 13, yield of loblolly pine on drained areas (800 cu. ft./ac.) was 10.5 times greater than on undraine areas (76 cu. ft./ac.).

Such responses are not limited to loblolly pine. In a study in Georgia on a Bayboro-Bladen

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[1] This paper is based on talks given in Raleigh, NC, November 8, 1977, at the Site Preparation Workshop (East) sponsored by the USDA For. Serv., Southeast. Area State and Private Forestry, and the North Carolina Forest Service, at the Edisto Chapter Meeting, Soc. of Amer. For., Feb. 9, 1978, in Charleston, SC, and at the For. Tree Nutrition Workshop, May 2, 1979, Bainbridge, Ga.

[2] Authors are principal silviculturist and principal soil scientist, respectively, USDA, For. Serv., Southeast. For. Expt. Stn., Forestry Sciences Laboratory, Charleston, SC, 29407.

kville soil association, Brightwell (1973)
owed that drainage of 7-year-old slash pine
. *elliottii* Engelm.) increased the average
ee growth by 4.2 fold at age 15. Thus, con-
derable evidence is accumulating that lowering
e average water table 1 to 1½ feet on extremely
t sites with poor natural drainage greatly
creases the growth of both loblolly and slash
nes.

SOIL-SITE WORK

In marked contrast to the results of drain-
studies, soil-site work by Coile (1952),
ser (1950), and Metz (1950) in the Atlantic
stal Plain of Virginia and the Carolinas
wed that site quality for loblolly pine was
her on poorly drained than on well-drained
ls. As Wahlenberg (1960) has pointed out,
s trend, although surprising and seemingly
adoxical, was also apparent in Louisiana
igsby 1952).

How can we explain the apparently contra-
tory results from the drainage and soil-site
k? One possible explanation for the effect of
l drainage on productivity is that the response
curvilinear as one goes from well to poorly
ined sites, that it peaks at some level of
ural drainage and then drops off sharply, that
le and his colleagues were working at one end
the curve, and that those involved in drainage
e working at the other. This explanation is
bably accurate, but how then do we explain
ductivity differences in the same drainage
ss or even in the same soil series (Soil
servation Service 1975)?

In three flatwood soil series--Craven, Wahee,
Meggett--we accounted for between 60 and 74
cent of the variation in site index of lob-
ly pine on the basis of soil properties (McKee
97). Current Soil Conservation Service guide-
es place these three series in drainage
sses ranging from moderately well to poor on
basis of the physical and chemical properties
the soil. Nitrogen, clay content, and soil pH
the A1 horizon accounted for 60 percent of the
iation in site index on moderately well drained
ven soil; nitrogen, calcium, and phosphorus in
B2 horizon accounted for 64 percent of the
iation on the somewhat poorly drained Wahee
s; and percentage of sand and available phos-
rus in the A1 horizon accounted for 74 percent
the variation in site index on the poorly
ned Meggett soil. Within a series, these
s varied as much as ± 20 feet in site index,
cating that chemical properties and texture
e a pronounced effect on site productivity.

BEDDING RESPONSES

Growth response of slash and loblolly pines to bedding, which provides microsite drainage, ranges from excellent to none. Bethune (1963), Langdon (1956, 1962), Malac and Brightwell (1973), Mann and Derr (1970), McMinn (1969), McKee and Shoulders (1970), and Pritchett and Smith (1974) have reported excellent response of slash and loblolly pines to bedding at young ages on wet sites. However, Haines, et al. (1975) and Lennartz and McMinn (1973) have reported that bedding responses may decrease as a stand grows older. And Derr and Mann (1970), Klawitter (1970), Malac and Brightwell (1973), and Terry and Hughes (1975) have reported little or no response on specific sites.

Explanations by the authors for these varying responses of slash and loblolly pines to bedding on wet sites have been largely speculative. When responses are positive, the reasons given include improved drainage, better soil aeration, better weed control, concentration of topsoil in the bed, and increased amount and availability of nutrients. When responses are negative, such reasons as the creation of a drought stress during summer months and poor bed construction are proposed.

The negative responses can be partially explained by the results of Terry and Hughes' (1975) factorially designed study of bedding and phosphate fertilization. They found that bedding on a poorly drained Bladen soil increased growth of loblolly pine only by 4 percent, that phosphate fertilization increased growth by 58 percent, and that bedding combined with phosphate fertilization increased growth by 168 percent. Their results illustrate Liebeg's law of the minimum as described by Kramer and Kozlowski (1960, p. 468):

> "The principle of limiting factors, as proposed by Blackman, states that if a process is affected by a number of separate factors, its rate is limited by that factor which is present in least amount relative to its minimum requirement."

Thus, in Terry and Hughes' study, lack of phosphorus was so limiting that the drainage provided by bedding did not increase growth until the nutrient deficiency was corrected.

The interaction of drainage and nutrition has been reported for soils in the Atlantic and Gulf Coastal Plain. Pritchett and Llewellyn (1966) observed that a surface application of phosphorus stimulated slash pine growth on imperfectly and poorly drained soils deficient in this element but had less effect on phosphorus-deficient soils that were better drained. Mann and McGilvray (1974) showed a similar response in northwest Florida with direct-seeded slash pine which at 8 years had responded about equally in height growth to bedding and phosphorus fertilization on poorly and very poorly drained Plummer soils. An additive response was found when bedding and phosphorus were combined. On the better drained Plummer soils, the trees did not respond to phosphorus.

TREE NUTRITION

Problems with nutrition on poorly drained soils are not unique to forestry. Van't Woudt and Hagan (1957) indicate that most field crops injured by high water tables have much higher nutrient demands when the soil is poorly aerated. Crops such as rice, which are adapted to poor soil aeration, are an exception. The reasons for increased nutrient requirement of trees and field crops subjected to waterlogging are not completely understood, but the higher nutrient requirement may result from restricted root systems. Kramer (1951a) found that flooding and poor aeration disrupted metabolism and reduced transpiration of herbaceous plants. Lorio, et al. (1972) showed that loblolly pines growing on flats had less fibrous root systems than those growing on low mounds.

Lack of aeration apparently affects the functioning of roots of other tree species in a similar manner. Shoulders (1976), working with slash pine seedlings, has demonstrated that reducing the oxygen level from 90 to 50 percent of equilibrium saturation with air reduced the root uptake of water, phosphorus, potassium, calcium, and magnesium but increased the uptake of nitrates.

Adaptation of lodgepole pines (*P. contorta* Dougl.) to poorly drained sites has been demonstrated. When subjected to waterlogging, roots of this species develop the ability to transport oxygen from the stem to root tissues (Philipson and Coutts 1978). This mechanism may also be present in loblolly pine. Field observations (unpublished) reveal that seedlings develop considerably more roots in fertilized, waterlogged soils, than in those waterlogged but not fertilized. Poor root development may also be related to calcium deficiencies and the imbalance in Ca: Mg ratios (Lyle and Adams 1971).

SOIL CHEMISTRY

Waterlogging and anaerobic environments of soils with prolonged high water tables cause dramatic changes in the properties of soil nutrients and their availability to plants (Patrick 1978). Oxygen, supplied by the soil or through the root, is required for normal nutrient uptake. Other chemical processes, however, may contribute equally to low uptake in poorly aerated soil.

One of the most striking effects is on pH of acidic soils. After prolonged waterlogging the pH becomes nearly neutral; it returns to its acid state as the soil dries (McKee 1970). This effect is cyclic with the rise and fall of the water table. Thus, the chemical compounds in waterlogged mineral soils are reduced, and the soil becomes anaerobic but not acid (fig. 1). The degree of reduction in the soil solution that takes place with waterlogging is expressed as the oxidation-reduction (redox) potential, in which positive values represent an aerated soil and negative values represent a waterlogged soil.

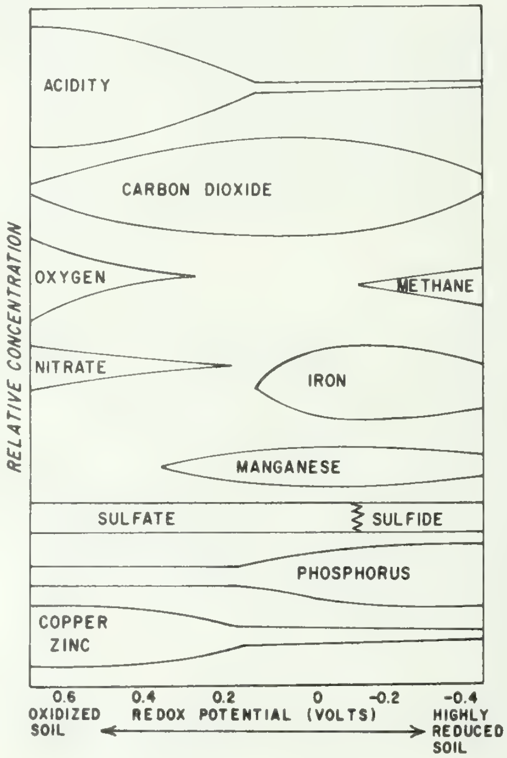

Figure 1.--Changes in relative concentrations of soil nutrients with waterlogging. Negative redox potentials indicate a high degree of waterlogging.

When the soil pores are saturated with wate only gases dissolved in water are present. Leve of oxygen are rapidly depleted by respiring microorganisms and roots of higher plants. Deficient aeration injures or kills the roots of man plants (Kramer 1951a). Simultaneously, levels o carbon dioxide increase until the soil solution is saturated with this gas (Ponnamperama 1972). This saturation is accompanied by a high content of carbonic acid and bicarbonates in the soil solution. As the soil becomes more anaerobic ar reduced, the metabolic activity of organisms is lowered and the degree of carbon dioxide saturation diminishes but remains a dominant influence on the soil solution. A buildup of carbon diox can reduce water and mineral absorption (Kramer and Kozlowski 1960).

Nitrates, if present in the soil, are duced soon after the oxygen is depleted, and e nitrogen is lost from the soil as a gas atrick 1978). Thus, it is not advisable to ply ammonium nitrate to poorly drained sites--e nitrogen will be lost rapidly to the atmos-ere.

One of the most obvious effects of water-gging is the reduction of iron and manganese the ferrous and manganous forms, which are luble (Patrick 1978). Both elements in their duced forms act as cations similar to calcium d thereby help to increase soil pH under water-gging.

When iron is solubilized in the ferrous form, tends to bring phosphorus into solution. Thus, longed or repeated flooding and solubilization phosphorus in forest soils may remove the trient from affected sites. When soils are xidized, the phosphorus may be tied up chemi-ly in a less available form (McKee 1970). thermore, trees with waterlogged roots may k the ability to use solubilized phosphorus ficiently (Kramer 1951b). However, such effects be corrected by the application of phosphorus a fertilizer. Why this is so is unknown; ever, we speculate that the effects are possi- related to ion antagonisms or ion pairing.

The presence of large amounts of reduced ganese in waterlogged soil poses a problem in e nutrition. However, it is uncertain whether ganese is directly toxic to trees or whether ion upsets the nutrient balance. The buildup the reduced metals could have effects on root tems similar to respiration inhibitors (Kramer lb). Higher nutrient levels may allow plants develop alternate metabolic pathways which ass the toxic metals. In either case, this dition can be corrected by the application of e, which lowers the concentration of manganous s in waterlogged soil.

Calcium and magnesium levels increase in erlogged soil because of the high concentration carbon dioxide. The exact effect of these ctions on mineral nutrition is ill-defined, apparently leaching is increased, leading to oss of exchangeable bases (McKee 1980). These ctions may account for the growth response to e on poorly drained soils as reported by Carthy and Davey (1976) and Langdon and Hatchell 77).

In waterlogged soils, trace elements such as per and zinc decrease in concentration as they precipitated as insoluble hydroxides, primarily ause of the increase in pH. They also form oluble sulfides in the presence of hydrogen fide. This gas, which is evident in the strong r of swamp soils, is formed by the reduction of fate during prolonged waterlogging (Ponnamperama 2). Drainage of waterlogged soils containing high concentrations of hydrogen sulfides (cat clays) results in extremely low pH values (<2) when the sulfides reoxidize to sulfuric acid. Prolonged waterlogging may also reduce the organic matter in soil to methane (swamp gas).

RELATIONSHIP OF SITE PRODUCTIVITY TO SOIL MOISTURE AND NUTRIENTS: A HYPOTHESIS

From the work reviewed, we have developed a working hypothesis on the relationship of site productivity to soil moisture and nutrients. Figure 2 illustrates this hypothesis. Briefly, site productivity is dependent on soil moisture and nutrient availability and their interactions. On very dry sites, nutrition is less critical than moisture because the latter is most limiting to growth. As moisture becomes more plentiful, nutrition plays a greater role in determining productivity. When a site becomes too wet, however, chemical reactions and lack of oxygen change the availability of nutrients, in some cases causing nutrient deficiencies of toxicities.

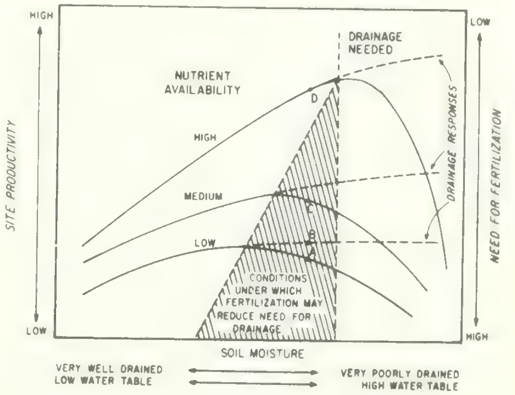

Figure 2.--Hypothesized relationship of site productivity to soil moisture and nutrients availability, the need for drainage and fertilization, and conditions under which fertilization may reduce the need for drainage.

Because of these relationships, we propose that fertilizing may greatly increase productivity of sites which are low in nutrients, poorly drained, and seasonally waterlogged (see shaded are in figure 2). For example, we hypothesize that draining a site with nutrient availability and moisture conditions as at point A in figure 2 would raise productivity to point B, but that fertilizing this same site to a medium or high nutrient level would raise productivity points to C or D without any drainage. We have demonstrated a similar response on a wet flat or savannah type (Langdon and Hatchell 1977). In a planting of several pine species on this unfertilized area, the best trees at age 11 were only about 12 feet tall, indicating that the site index was not more than 50 feet. Fertilization with phosphate and lime at age 11, and with nitrogen at age 14, converted the plots by age 17 to a site index of 85 feet. Admittedly, this is only one example, and it certainly does not indicate that our results are universally applicable. However, in discussing the work of the University of Florida's Forest Fertilization Cooperative, Bengtson (1971, p. 53) also observed that "appropriate fertilization may in the less waterlogged situations, obviate the need for drainage by stimulating early rapid growth of the pine stand." He pointed out that transpiration from such a stand "improves local drainage with ever-increasing benefits to root development and nutrient cycling."

Thus, our answer to the question of whether fertilization of loblolly or slash pine can reduce the need for drainage is a qualified "yes", especially if soil and foliar tests indicate deficiencies in phosphorus, calcium, nitrogen, or other nutrients. We realize that much more work is needed to test this working hypothesis; however, the evidence is strong enough for landowners to pilot-test this concept on wet sites that are apt to show response. Soils associated with such sites frequently have a dark surface horizon, and are classed as umbric aquults or groundwater spodsols. Mottling approaches the soil surface, and profile development is frequently weak and tongued. Water is normally present at or near the soil surface for several months each year. Ericaceous vegetation is usually more abundant here than on adjacent sites, and pines appear stunted and have short needles. Wet pine flats and savannahs are names often given to such sites.

The potential benefits to a landowner of fertilizing the sites in question would be to change low or nonproductive sites to ones of higher productivity at a relatively low cost with only minor soil disturbance and minimal use of heavy equipment.

LITERATURE CITED

Bengtson, G. W.
1971. Pruning, irrigation, drainage, and fertilization: Their current trends in southern pine silviculture. In Southern pine management--today and tomorrow. 20th Annu. For. Symp., La. State Univ., Baton Rouge., pp. 47-68.

Bethune, J. E.
1963. Ridging: Low-cost techniques for increasing growth on wet flatwoods sites. For. Farmer 23(3): 6-8, 18.

Brightwell, C. S.
1973. Slash pine plantations respond to water control. Union Camp Corp. Woodland Res. Note 26, 3 p.

Coile, T. S.
1952. Soil and the growth of forests. Adv. Agron. Academic Press Inc., N.Y., 4:329-398.

Derr, H. J., and W. F. Mann
1970. Site preparation improves growth of planted pines. USDA For. Serv., South. For. Expt. Stn., Res. Note SO-106, 3 p.

Gaiser, R. N.
1950. Relation between soil characteristics and site index of loblolly pine in the coastal plain region of Virginia and the Carolinas. J. For. 48: 271-275.

Grigsby, H. C.
1952. The relationship of some soil factors to the site index of loblolly pine in southeastern Louisiana. M.S. Thesis, La. State Univ. School For., Baton Rouge.

Haines, L. W., T. E. Maki, and S. G. Sanderford
1975. The effect of mechanical site preparatio treatments on soil productivity and tree (*Pinus taeda* L. and *P. elliottii* Engelm. var. *elliottii*) growth. In Forest soil and land management. Proc. Fourth North Amer. For. Soils Conf., Les Presses L' Universite', Laval, Quebec. pp. 379-395.

Klawitter, R. A.
1970. Does bedding promote pine survival and growth on ditched wet sands? USDA, For. Ser Northeast. For. Expt. Stn., Res. Note NE-109 4 p.

Kramer, P. J.
1951a. Causes of injury to plants resulting from flooding of the soil. Plant Physiol. 26: 722-736.

______ 1951b. Effects of respiration inhibitors on accumulation of radioactive phosphorus by roots of loblolly pine. Plant Physiol. 26: 30-36.

______, and T. T. Kozlowski
1960. Physiology of trees. McGraw-Hill Book Co., Inc., N.Y. 642 p.

Langdon, O. G.
1956. Elevation and tree growth. South. Lumberman 193(2417): 191-192.

______ 1962. Ridge planting improves early growth o South Florida slash pine. J. For. 60: 437.

angdon, O. G., and G. E. Hatchell
1977. Performance of loblolly, slash, and pond pines on a poorly drained site with fertilization at ages 11 and 14. In Proc. Sixth South. For. Soils Workshop, USDA, For. Serv., Southeast. Area State & Priv. For., Atlanta, Ga. pp. 121-126.

ennartz, M. R., and J. W. McMinn
1973. Growth of two varieties of slash pine on prepared sites in south Florida: 10-year results. USDA, For. Serv., Southeast. For. Expt. Stn., Res. Pap. SE-103, 10 p.

rio, P. L., Jr., V. K. Howe, and C. M. Martin
1972. Loblolly pine rooting varies with microrelief on wet sites. Ecology 53: 1134-1140.

le, E. S., Jr., and F. Adams
1971. Effect of available soil calcium on taproot elongation of loblolly pine (*Pinus taeda* L.) seedlings. Soil Sci. Soc. Am. Proc. 35: 800-805.

cCarthy, R., and C. B. Davey
1976. Nutritional problems of *Pinus taeda* (loblolly pine) growing on pocosin soil. Soil Sci. Soc. Am. J. 40: 582-585.

lac, B. F., and C. S. Brightwell
1973. Effect of site preparation on planted southern pines. Union Camp Corp. Woodland Res. Note 29, 9 p.

ki, T. E.
1955. The role of superior trees in forest management. Unit 58: 88-97.

______
1968. Drainage and soil moisture control in Forest Production. In The ecology of southern forests. 17th Annu. For. Symp., La. State Univ., Baton Rouge. pp. 139-157.

______
1971. Drainage: Effect on productivity. In Proc. 50th Annu. Meet., Appal. Sect., Soc. Amer. For., Charleston, SC, pp.16-23.

hn, W. F., and H. J. Derr
1970. Response of planted loblolly and slash pine to disking on a poorly drained site. USDA, For. Serv., South. For. Expt. Stn., Res. Note SO-110, 3 p.

______, and J. M. McGilvray
1974. Response of slash pine to bedding and phosphorus application in southeastern flatwoods. USDA, For. Serv., South. For. Expt. Stn., Res. Pap. SO-99, 9 p.

Kee, W. H., Jr.
1970. Chemical properties of a forest soil affected by fertilization and submergence. Soil Sci. Soc. Am. Proc. 34: 690-693.

McKee, W. H., Jr.
1977. Soil-site relationships for loblolly pine on selected soils. In Proc. Sixth South. For. Soils Workshop, For. Serv., Southeast. Area State & Priv. For., Atlanta, Ga., pp. 115-129.

______
1980. Changes in solution of forest soils with waterlogging and three levels of base saturation. Soil Sci. Soc. Am. J. 44: 388-391.

______, and E. Shoulders
1970. Depth of water table and redox potential of soil affect slash pine growth. For. Sci. 16: 299-402.

McMinn, J. W.
1969. Preparing sites for pine plantings in South Florida. USDA, For. Serv., Southeast. For. Expt. Stn., Res. Note SE-117, 5 p.

Metz, L. J.
1950. Relationship between soil properties and the growth of loblolly pine in the southeastern coastal plain. M. S., Ph.D. Thesis, Duke Univ. Sch. For., Durham, N.C. 51 p.

Miller, W. D., and T. E. Maki
1957. Planting pines in pocosins. J. For. 55: 659-663.

Patrick, W. H., Jr.
1978. Chemistry of flooded soil and effects on mineral nutrition. In Proc. Soil Moisture-Site Prod. Symp., USDA, For. Serv., Southeast. Area State & Priv. For., Atlanta, Ga., pp.40-48.

Philipson, J. J., and M. P. Coutts
1978. The tolerance of tree roots to waterlogging. III. Oxygen transport in lodgepole pine and Sitka spruce roots of primary structure. New Phytol. 80: 341-349.

Ponnamperama, F. N.
1972. The chemistry of submerged soils. Adv. Agron. Academic Press, Inc., NY, 24: 29-96.

Pritchett, W. L., and W. R. Llewellyn
1966. Response of slash pine (*Pinus elliottii*) Engelm. var. *elliottii*) to phosphorus in sandy soils. Soil Sci. Soc. Am. Proc. 30: 509-512.

______, and W. H. Smith
1974. Management of wet savannah forest soils for pine production. Univ. Fla. Agr. Expt. Stn., Gainesville, Bull. 762, 22 p.

Pruitt, A. A.
1947. Study of effects of soils, water table, and drainage on height of slash and loblolly pine plantations on the Hofmann Forest. J. For. 45: 836.

Ralston, C. W.
1965. Forest drainage. In A guide to loblolly and slash pine plantation management in southeastern USA. Ga. For. Res. Counc. Rep. 14: 298-319.

Shoulders, E.
1976. Poor aeration curtails slash pine root growth and nutrient uptake. USDA, For. Serv., South. For. Expt. Stn., Res. Note. SO-218. 5 p.

Soil Conservation Service
1975. Woodland soil survey interpretations, South Carolina. USDA, Soil Conserv. Serv., Columbia, SC, 46 p.

Terry, T. A., and J. H. Hughes
1975. The effects of intensive management on planted loblolly pine (*Pinus taeda* L.) growth on poorly drained soils of the Atlantic Coastal Plain. In Forest soils and land management. Les Presses de L'Universite', Laval, Quebec. pp. 351-377.

Van't Woudt, B. D., and R. M. Hagan
1957. Crop responses at excessively high soil moisture levels. In Drainage of agricultural lands. Am. Soc. Agron. 7: 514-611.

Wahlenberg, W. G.
1960. Loblolly pine: Its use, ecology, regeneration, protection, growth, and management. Duke Univ. Sch. For., Durham, NC, 603 p.

ESTIMATING FERTILIZER RESPONSE IN SITE-PREPARED PINE PLANTATIONS USING BASAL AREA AND SITE INDEX[1]

Howard W. Duzan, Jr. and H. Lee Allen[2]

Abstract.--Periodic growth models formulated for untreated and fertilized stands using basal area and site index as predictor variables represent a unique system for characterizing and quantifying response to nitrogen fertilization. Response was found to increase with increasing basal area and decrease with increasing site index. The equations produced provide a basis for selection of candidate stands for fertilization while giving better estimates of response needed for economic evaluation.

INTRODUCTION

The use of nitrogen fertilizers to enhance rowth in Southern loblolly pine (Pinus taeda L.) lantations has steadily increased during the last ew years. Results from fertilizer trials covering wide range of soils and stand conditions in the outh have encouraged many forest managers to conider nitrogen fertilization as a viable silviculural tool. Although many trials have demonstrated ubstantial volume gains, some installations have ndicated little or no advantage from nitrogen ertilization and in some cases negative responses ave been reported. A method of characterizing hose sites which are more responsive to nitrogen ased on soil or stand parameters would greatly mprove the gains from an operational fertilization ogram while providing better estimates for eco- mic evaluation of proposed projects.

Efforts to diagnose sites which are responsive nitrogen using soil or foliar variables alone ve not produced acceptable results (Haines et al. 76). Much of the problem has been our inability determine the nitrogen fraction, in either soil foliage, that best reflects nitrogen availability the tree. Another consideration is the influ- ce of stand characteristics on response, in rticular, basal area per acre and site index at age 25. There are several reasons for looking at these two stand parameters. Basal area is a reflection of the needle biomass which is available to respond to fertilizer. Site index is a composite measure of the productivity of the stand, reflecting both soil physical and chemical properties as well as climate. Site index can also be viewed as an indicator of the severity of growth limiting deficiencies. If nitrogen is the limiting factor, site index should be related to a stand's responsiveness to nitrogen **application**.

Studies involving nitrogen fertilization of Douglas-fir (Pseudotsuga menziesii Franco) in the Pacific Northwest have shown that response is related to the stocking level of the stand at time of fertilization (Shumway and Atkinson 1978). Additional work with Douglas-fir suggests that response may be correlated with growth on the untreated stand (Anon. 1974). This point reemphasizes the importance of basal area and site index since periodic growth on any stand depends to a large extent on the growing stock and productivity of the site. In similar attempts to model response to nitrogen by Swedish researchers (Rosvall 1979), important independent variables were found to be site index, current untreated growth, age, nitrogen rate, latitude, and altitude.

A technique is described in this paper for predicting volume response to nitrogen fertilization in established loblolly pine plantations using basal area per acre and site index. The utility of any response model using these measures as independent variables is enhanced by the direct application of the model to existing inventory systems. Selection of candidate sites and evaluation of gains from a fertilization program can be accomplished with little effort. More precise diagnostic techniques for soil and foliar nitrogen levels can be incorporated into an existing basal area-site index model to more accurately estimate nitrogen needs for individual stands as they become available.

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PLOT DATA

Data selected for fitting the proposed model represent a subset of fertilizer trials established in 1971-73 by Forest Industry members of the North Carolina State Forest Fertilization Cooperative. Control plots and plots fertilized with 100 pounds of elemental nitrogen (as ammonium nitrate) per acre were chosen from 37 trials. Installations were selected to cover a wide range of stand conditions on a variety of soil types across the South. Further constraints included selection of stands which had been site-prepared and which had foliar phosphorus levels of .1% or greater. The range of stand conditions for selected trials is summarized in table 1. Measurements were made initially and after five years. Per acre volumes were calculated using a total stem, outside-bark equation for individual trees (Smalley and Bower 1968). Gross volume growth estimates were calculated using all trees and do not include losses to mortality.

Table 1.--Summary of stand conditions for trials included in the data set (37 trials with paired treatments, total observations = 74).

Variable	Mean	Std.Dev.	Range
Age (yrs)	12	4	5-18
Site index (25 yr,ft)	63	10	45-90
Stems/ac.	754	163	397-1165
BA/ac. (ft^3)	86	52	6-174
Foliar N (%)	1.16	.13	.88-1.39
Foliar P (%)	.14	.04	.10-.20

A MODELING APPORACH

Modeling of fertilizer response can be accomplished through several avenues. The traditional method is to calculate periodic volume response (fertilized minus control) for each trial and relate this measure to the initial stand parameters using regression techniques. A problem arises in that fertilized and control plots may or may not be comparable due to differences in stand characteristics prior to treatment. Covariance analysis can be applied using this method to adjust for initial conditions prior to calculating response. Another approach to assessing response is to determine the impact of nitrogen fertilization on the growth trends of fertilized stands.

Five-year volume growth on the control plots was relaced to initial basal area and site index using a growth model which was developed from biological principles. Scatter diagrams of raw data were used to substantiate the growth model used. Fertilized plots were included in the model and dummy variables were used to statistically tes for changes in the coefficients of the untreated model which resulted from inclusion of the fertilized plots. All possible combinations of treatment influence on the model were examined. Coefficients for the basal area and basal area x site index terms in the denominator of the model were found to be significantly altered by application of nitrogen fertilizer. Other coefficients in the model were not significantly altered. The equation produced using this technique provides a method for determining how nitrogen fertilizer changes the periodic growth pattern on treated stands. In addition, estimates of periodic volum growth for both treated and untreated stands of known basal area and site index can be calculated The combined model for both untreated and fertilized stands is:

$$\text{Growth} = (52.61087 + \text{BA})/(0.124105 + 0.0003557* - 0.001027*\text{SITE} - 0.00000006*\text{BA}*\text{SITE} - 0.0005146*\text{BA}*T_1 + 0.00000601*\text{BA}*\text{SITE}*T_1)$$

Where: Growth = 5-year gross volume increment (cu.ft/acre)
BA = initial basal area (sq.ft/acre)
SITE = 25-year site index (ft)
T_1 = treatment effect,
T_1 = 0 for untreated
T_1 = 1 if fertilized with N10

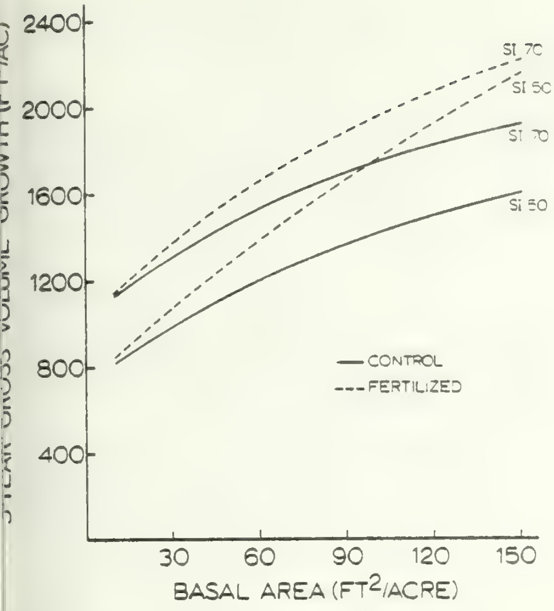
R^2 for combined model = .73
Standard Error of mean = 31 cu.ft/acre

Analysis of sequential sums of squares for the combined growth model revealed that basal area accounted for 56% of the total corrected variati inclusion of site index accounted for an additic 11%, and the treatment effect produced a further reduction of 6%. All included effects were statistically significant ($\alpha = .05$).

Growth curves developed from the above equa for untreated and fertilized stands at two site index levels are illustrated in figure 1. Note the basic shape of the periodic growth curves u untreated conditions and the changes which occu when nitrogen is applied. Estimates of respons to nitrogen over control derived from the compo growth equation are presented in table 2 for a of basal areas and two site indices.

DISCUSSION AND CONCLUSIONS

The data, illustrated in figure 2 and presented in table 2, demonstrate the relationshi between response and stand parameters over the range normally found in managed plantations. most obvious trends are decreasing response as index increases and increasing response as bas area increases. In order to explain these res we must consider first the attributes of the d set used to fit this model. Phosphorus-defici sites and poorly-drained or excessively draine sites which are major factors contributing to site quality in much of the South were not inc



igure 1.--Five-year periodic growth predictions for untreated and fertilized stands (100 lbs N/ac) using basal area at two levels of site index.

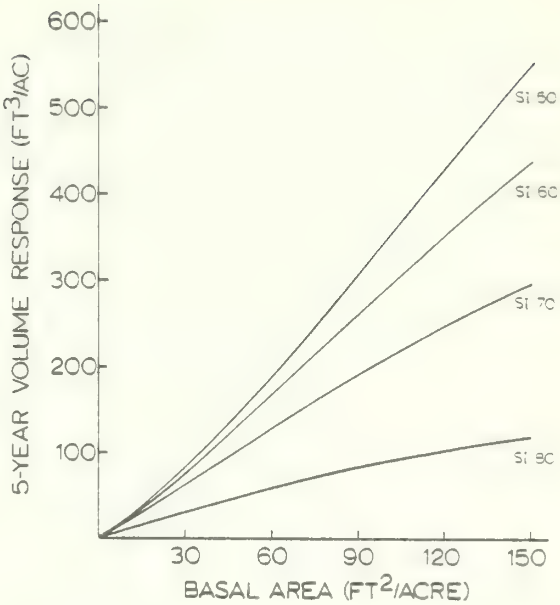


Figure 2.--Relationship of basal area and site index to five-year volume increment over control for stands fertilized with nitrogen. (Based on fitted growth equations.)

Tble 2.--Five-year gross volume response (cu.ft/acre) with application of 100 pounds of elemental nitrogen.

asal Area (q.ft/acre)	Site Index (ft) 50	60	70	80
10	24	23	19	10
30	83	76	62	31
50	153	136	106	50
70	229	199	149	68
90	309	261	191	84
110	390	323	230	98
130	472	383	266	110
150	554	440	299	121
170	634	496	331	131

th removal of these factors as primary influences site productivity, the data suggest that the imiting factor may be nitrogen. The simple correlation between site index and foliar nitrogen percent (r = .48) was positive and statistically gnificant (α = .01). We speculate that high site ices are associated with areas having a favorable trogen status, thereby providing a reasonable planation for lower responses to nitrogen on ands with higher site index.

Poor response to nitrogen on stands of low basal ea (10-30 sq.ft/acre) is to be expected. The lack an adequate growth base to give quantitative pression to the response, coupled with uptake of trogen by competing vegetation, make fertilization of very young stands inefficient. As stands become more developed and approach crown closure (50-90 sq.ft. of basal area), a larger response to nitrogen can be anticipated. Response continues to increase according to this model, as basal areas approach 150 square feet per acre. Biologically, we might expect that as stands become fully to overly-stocked, response to nitrogen, measured as gross volume growth per acre, would level off or possibly decrease, since crown surface area would be at a maximum (Tamm 1979). This trend cannot be substantiated using the fitted model since very few of the site-prepared stands were heavily enough stocked to determine if response in fact declines at higher basal areas.

Extrapolation beyond the ranges of the original data set may produce erroneous estimates of response. This limitation applies not only to basal area and site index but other parameters as well. Population conditions which must be satisfied include stands which are:

1) site-prepared loblolly pine plantations,
2) not P-deficient or have had phosphorus applied prior to planting,
3) naturally well drained or were artificially drained prior to planting,
4) exclusive of excessively drained, sandy sites.

The relationship between site index and response to fertilizer is particularly sensitive to the population of stands used to fit the model. In the case of this model, the data set used was quite restricted, being taken from stands on non P-deficient sites exhibiting a narrow range of drainage classes. The result was a negative relationship between site index and response probably reflecting a dominant influence of N status on site index for this population. A similar model, being published in the Southern Journal of Applied Forestry (Duzan et al. 1980), and fit using older, essentially old-field stands covering a wide range of soil P and drainage conditions, gave a positive relationship between site index and response. This probably reflects the restrictive effect of extreme drainage conditions and P-deficiency on N response in the low site index range. This apparent difference does not reduce the validity of either model, but rather emphasizes the importance of selection of the appropriate model for various stand conditions.

Two further points in regard to the use of the presented growth model should be considered. First, incremental response from nitrogen fertilizer is estimated over a five-year growth period. Some additional gains may occur after five years, particularly in young, low basal area stands. Secondly, the recommended optimum application rate for nitrogen is 150 pounds per acre which it is estimated will increase response approximately 15% over those estimates in table 2 (NCSFFC 1980).

Although this data set is quite restricted, it does represent a large acreage of plantations in the South. As future regeneration efforts concentrate on cut-over sites and corrections for phosphorus deficiencies and poor drainage improve productivity on many areas, the utility of this model for characterizing stands responsive to nitrogen will increase.

LITERATURE CITED

Anon. 1974. Biennial Report. Regional Forest Nutrition Research Project, 1972-1974. College of Forest Resources. University of Washington.

Duzan, H. W., Jr. and H. L. Allen. 1981. Predicting fertilizer response in established loblolly pine plantations with basal area and site index. Sou. J. of Applied Forestry (in press).

Haines, L. W., S. G. Haines, and V. H. Allen, Jr. 1981. Predicting fertilizer response in established loblolly pine stands. p. 57-77. In W. E. Balmer (ed). Proc. 6th South. For. Soils Workshop. USDA For. Serv. Southeast Area State and Priv. For., Charleston, S.C.

NCSFFC Report No. 7. 1980. Optimum nitrogen rates for fertilization of loblolly pine plantations. School of For. Resources. N. C. State Univ. Raleigh, N.C. (Unpublished)

Rosvall, Ola. 1979. Prognosfunktioner för beräkning av gödslingseffekter Föreningen Skogsträdsförädling, Institutet for Skogsförbättring, Årsbok.

Shumway, J and W. A. Atkinson. 1978. Predicting nitrogen fertilizer response in unthinned stands of Douglas-fir. Commun. Soil Sci. Plant Anal. 9: 529-539.

Smalley, G. W. and D. R. Bower. 1968. Volume tables and point sampling factors for loblolly pine in plantations on abandoned fields in Tennessee, Alabama, and Georgia Highlands. USDA For. Serv. Res. Pap. SO-32. 13 p. Sou. For. Expt. Sta. New Orleans, La.

Tamm, C. O. 1979. Nutrient cycling and productivity of forest ecosystems. p. 2-21. In A. L. Leaf (ed.). Proc. Impact of Intensive Harvesting on Forest Nutrient Cycling. SUNY College of Forestry. Syracuse, N.Y.

Wells, C. G. 1968. Techniques and standards for foliar diagnosis of N deficiency in loblol pine. p. 72-76. In Forest Fertilization- theory and practice. TVA. Muscle Shoals, A

NITROGEN FERTILIZATION OF ESTABLISHED LOBLOLLY PINE STANDS:

A FLEXIBLE SILVICULTURAL TECHNIQUE[1/]

R. Ballard[2/]

Abstract.--Results are presented which resolve many of the uncertainties regarding suitable nitrogen (N) fertilizer sources and effective rates and times of application for fertilizing loblolly pine plantations. Recent developments in fertilizer response prediction technology are covered. The potential for using N fertilization to manipulate fiber supply and size classes of timber is discussed.

INTRODUCTION

Nitrogen (N) fertilization of established sands is a well accepted silvicultural technique i the Pacific Northwest (PNW) but its acceptance i the South has been much slower. Currently abut 300,000 acres are fertilized with N annually i the PNW while only ca 60,000 acres are fertilied annually in the South (Bengtson 1979) and mst of this is on one ownership. This is not an idication that responses to N are greater or more fequent in Douglas-fir than in the Southern pine frests: evidence indicates that average responses oer a range of sites in both regions are remarkaly similar (Miller & Fight 1979; Haines et al 179). There appear to be two major factors rtarding operational use of N fertilizers in etablished Southern pine plantations. These I wll label as the P-resonse syndrome and the tchnology gap.

ACCEPTANCE PROBLEM

PResponse Syndrome

The South is unfortunate in more ways than oe in having some extremely P-deficient forest soils in the Lower Coastal Plain region. Not only do resources have to be committed to ameliorate the problem on these soils but the type of response achieved has unfortunately set standards of acceptance among many forest managers for fertilizer response. Phosphorus deficiency is very much a problem of young developing plants and its correction invariably produces visually spectactular responses. We have all seen these responses in the field or in publications (Pritchett & Smith 1974) where P fertilization makes the difference between having or not having a plantation.

Based on results from an extensive series of trials in loblolly pine plantations throughout the South, it is apparent that the productivity of most plantations are limited to some extent by N deficiencies (table 1). The responses obtained, which average about 2 cords/acre over a 4 to 5 year period after fertilization, but range up to about 8 cords per acre, are commercially viable in many cases. However responses of 2 to 5 cds/acre are difficult to "see" in plantations with 15 to 30 cds/acre of standing timber. These non-visual responses in apparently healthy plantations are difficult to sell to managers accustomed to thinking of fertilization as an all or nothing remedial measure. The challenge in the South today is to sell N fertilization as an investment opportunity, not as a remedial measure.

Technology Gap

Even where forest managers can be sold on the benefits and opportunities of N fertilization, they still need and demand certain information before going operational. Because most managers have only limited financial resources at their

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Table 1.--Average volume gains, by physiographic regions, for loblolly pine plantations fertilized with either 150 or 100 lbs N per acre

Treatment	Piedmont	Upper Coastal Plain	Lower Coastal Plain	All Sites	Range
	--------------------(4-yr cu.ft/acre gain)----------------------				
150N[1]	189 *(24)* [3]	157 *(6)*	235 *(22)*	205 *(52)*	-44 to 552
	--------------------(5-yr cu.ft/acre gain)----------------------				
100N[2]	219 *(47)*	155 *(43)*	126 *(53)*	166 *(142)*	-229 to 802

[1] Any P deficiency corrected by fertilization. Plantations had an average age of 12.3 yrs with a range from 2 to 21 years; initial basal area averaged 88 sq. ft/acre with a range of 0 to 291 sq.ft/acre.

[2] Any P-deficiency not corrected. Plantations had an average age of 12 yrs with a range from 2 to 35 years; initial basal area averaged 102 sq.ft/acre with a range of 0 to 223 sq.ft/acre.

[3] Values in parenthesis indicate number of fertilizer trials.

disposal their first requirement is to be able to identify sites where the largest and most profitable responses will be obtained from N fertilization. In addition he needs to know what source of fertilizer to apply, when to apply it and the most economical rate to apply. Lack of suitably accurate techniques for predicting quantitative responses to N fertilization and uncertainty over effective fertilizer sources, rates and times of application has undoubtedly contributed to the slow acceptance of operational N fertilization in the South.

Recent information generated from the extensive number of N fertilizer trials installed by Forestry Industry members of the North Carolina State Forest Fertilization Cooperative (NCSFFC) goes a considerable way towards resolving many of the above uncertainties.

STATE OF THE ART

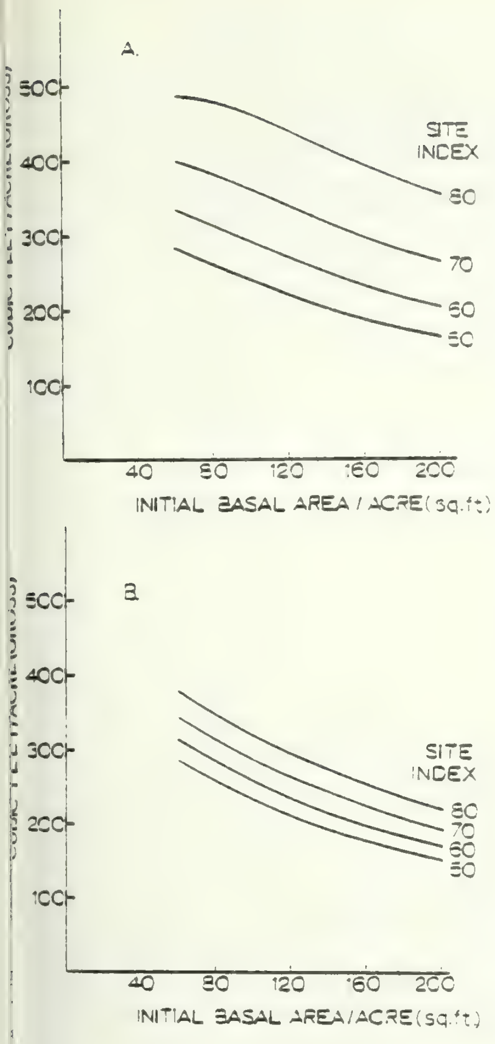
Prediction of Response

Attempts to predict N fertilizer response in forest plantations have in the past centered on measurements of N in the soil or plant tissues. These traditional methods have largely proved unsuccessful at predicting the quantitative response to N fertilization (Ballard 1980).

As response information became available from NCSFFC N-fertilizer trials covering a wide range of both stand and soil conditions, it became apparent that the quantitative response was associated more with stage of stand development than soil variables. This is perhaps not surprising in view of the ubiquitous nature of N deficiencies throughout the loblolly pine range and the obvious role the stage of stand development plays in setting growt limits.

Models have been developed using basal area and site index, for predicting the magnitude of N fertilizer response in older, mainly old-field loblolly pine plantations (Duzan et al 1981; fig. and for younger, site prepared plantations (Duzan and Allen 1980). These models are compatible with most inventory systems which enables site selection for N fertilization without additional field sampling and also provides the opportunity for evaluating various N fertilization strategies in relation to ownerships production and product goals. While these models are effective at predicting the average response to be expected fro N fertilization of various stand types, predictio for specific sites are subject to quite a wide margin of error. Theoretically a better predictio of response magnitude should be possible from a model which identifies sites according to both their N status and stand variables that control the potential periodic increment of the stand o a 5 to 7 year period following fertilization. Enhanced growth rates in N-fertilized forest plantations typically persist for only 5 to 7 years (Ballard 1981a). Work is underway within NCSFF to develop such a model.

With the large value differentials betwee pulpwood and logs used for solid wood products, most loblolly pine stands harvested are now merchandized according to diameter classes. Consequently, most forest managers would like to kno more than just the total volume response from fertilizing a stand. For the purpose of determining profitability, they would also like to know the distribution of the volume response among diameter or merchantability classes. This type f information is obtainable using an individual e



Igure 1.--Influence of initial basal area and site index (25 yr) on 5-year gross volume response from fertilization of loblolly pine plantations with 100 lbs N + 50 lbs P/acre in the Lower Coastal Plain (A) and Piedmont (B) regions (Duzan et al. 1981).

alysis approach: using regressions of volume owth on diameter class for both fertilized d unfertilized stands, the fertilizer response either initial or final diameter classes can determined (fig. 2). We have identified rtain trends in response distribution patterns ich appear to be related to the stage of stand velopment (Rogers 1978): in young, open grown ands response tends to occur equally among the ameter classes; in stands exhibiting some crown mpetition response tends to be greater in larger ameter classes; and in severely overstocked ands response in larger diameter classes tends be off-set by suppression of growth in smaller ameter classes. Our objectives now are to define ose stand and site conditions which show common ends and to mesh response distribution predictions th cur gross volume prediction models.

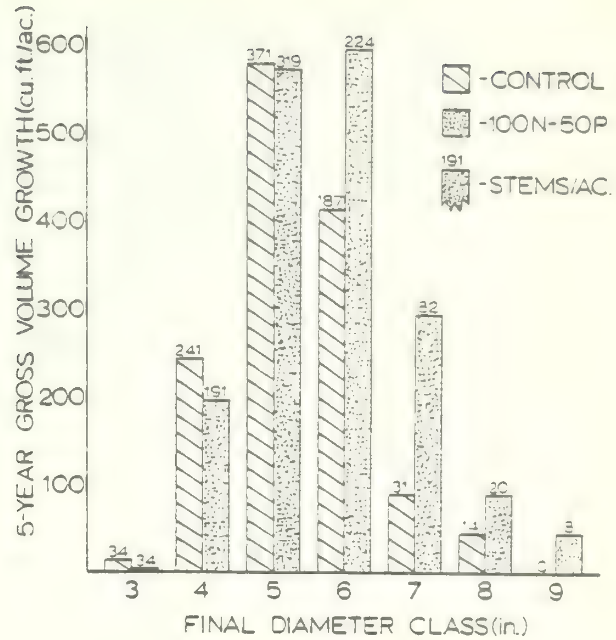


Figure 2.--Five-year volume growth per acre by final diameter class following fertilization of a 9-year-old loblolly pine plantation with 100 lbs N + 50 lbs P per acre.

Fertilizer Sources

In forestry, the choice of a N fertilizer is essentially between ammonium nitrate (AN) and urea (U). Other N sources are available, but high costs per unit of N or low analysis values, which increase handling and application charges, tend to preclude their use for operational fertilization of forest stands (Bengtson 1976).

A comparison of AN and U, applied at 150 lbs N/acre over a wide range of site and stand conditions throughout the South, revealed no significant differences in effectiveness of these two sources Ballard, 1981b): differences in response between the two sources were small in relation to the magnitude of the response to N (table 2). Either source is acceptable for fertilization of loblolly pine plantations and the choice should rest on such considerations as local availability, price, and cost of application.

Timing of Application

Seasonal--In the trial series comparing AN and U, these N-fertilizer sources were applied at 3 times of the year. Results showed significant differences in response between application dates at 3 out of the 11 sites (table 2). The difference at all 3 sites was associated with a significantly poorer response from the summer (June) application of both N sources (Ballard 1981b). Soil and stand conditions appear to be unrelated to the effectiveness of summer applications: it is suspected that the higher probability during summer of heavy rains, Table 2.--Main effects of nitrogen fertilizer sources and time of application on 4-year volume response in loblolly pine plantations.

Trial no.[1]	Source[2]			Time of Application[3]		
	AN	U	AN-U	Feb.	June	Oct.
	(cu.ft/acre)					
1	15	84	-69	33	107	7
4	168	169	-1	162	180	164
6	340	285	65	331	287	317
7	522	497	25	549a	425b	554a
9 (T)	283	308	-25	330	248	308
9 (UT)	191	155	36	106	-	240
11	235	314	-79	345a	165b	313a
15	169	171	-2	167	173	-
16	125	125	0	123	140	113
19	130	81	49	158a	12b	147a
24	178	118	160	139	195	110
Avg.	214	210	4	222	193	227

[1] NCSFFC trial code. For details of individual trial site and stand conditions see Ballard (1981b).

[2] Ammonium nitrate (AN) and urea (U).

[3] Treatments within rows not followed by a common letter differ significantly ($P < 0.05$). Treatment differences non significant in rows without letters.

capable of leaching N from both sources, accounts for the apparent randomness of the sites showing an inferior response to summer applications.

It is recommended that AN and U be applied in either spring or autumn. Our knowledge of N behavior in soils also leads us to recommend that even within these seasons, applications should be avoided when 1) the ground is water-logged, 2) long, dry hot spells are forecast, and 3) torrential down-pours are likely within a few days of application. Although we have not tested winter applications, theoretical considerations suggest that N fertilizer effectiveness might be reduced by application during this season, particularly in cold areas subject to snow accumulations and on wet sites, due to high leaching and denitrification losses.

Stage of Stand Development--Our fertilizer response prediction models indicate as in figure 1 that periodic (5 years) response increment is related to basal area. The precise nature of the relationship is not clear in the middle range of basal areas but it is clear that much smaller quantitative responses are obtained if N fertilizer is applied when the stand is either very understocked (< 20 sq.ft/acre basal area) or severely overstocked (> 160 sq.ft/acre basal area.)

Optimum Rates of Application

Trials designed to determine optimum N rate for fertilizing loblolly pine plantations have shown optimum rates to be fairly independent of site and stand conditions (Ballard, 1981a). For 11 out of 17 N-rate studies which showed a significant response to N fertilization, the average N rate which maximized volume response (biologic optimum) was 200 lbs N/acre (table 3). Based on assumed pulpwood and sawlog stumpages of $0.20 and $0.70 per cu.ft., respectively, average economic optimum N-rates for capture of the total response on either pulp or sawlogs wer calculated to be 57 and 152 lbs N/acre, respecti The standard error for the average sawlog optimum was only ±10 lbs N/acre. Because of th

Table 3.--Estimated optimum N application rates and their associated volume responses for loblolly pine plantations.

Trial[1/] No	Optimum N application rate: Economic: Pulpwood	Optimum N application rate: Economic: Sawlog	Optimum N application rate: Biologic	Volume response: Pulpwood	Volume response: Sawlog	Volume response: Biologic
	(lbs N/ac)			(cu.ft/ac)		
21	13	134	182	27	183	195
51[2/]	84	219	354	194	397	463
62	82	128	147	267	327	333
81[2/]	0	172	256	0	199	224
82	64	156	200	245	427	502
111	94	168	198	274	368	378
151	64	156	200	186	357	380
152	100	145	163	362	420	425
161[2]	20	183	248	42	252	271
191	42	105	131	104	185	193
231	61	105	122	184	240	245
Avg.	57	152	200	171	309	328

[1/] NCSFFC trial code. For details of individual trial site and stand conditions see Ballard (1981a).

[2/] Based on four-year response information. All other trials based on five-year response information.

eatively small variation about average optimum aes, the difficulty of uniformly applying etilizer under operational conditions and the yically large within site variability of most oest management units, standarized application aes are recommended for specific silvicultural eimes.

nowns

Fertilization has been incriminated in in- rasing the incidence of diseases such as uiform rust and pitch canker and the degree of aage from snow and ice. We do have evidence Ke 1980) that N fertilization of loblolly pine ltations greater than 2 years of age does not nrease fusiform infection rates or associated aage. Effects on the incidence of other iases and pests attacks are largely unknown.

In very few cases do we have any evidence to uort the contention that N fertilization nreases the degree of damage from ice and snow. u of the several hundred NCSFFC fertilizer trials hughout the South, we have only two trials in hh the degree of ice damage has been obviously eated to N fertilization.

The interactions between N fertilization and tr silvicultural operations in loblolly pine ltations, particularly thinning and prescribed uing, are not well understood. While we have found that on the average thinned stands of loblolly pine respond somewhat more than unthinned stands (table 4), it is not a consistent trend. The nature of this interaction is examined in another paper at this Symposium (Ballard, et al. 1980).

Table 4.--Average 4-year volume increment from thinning x N fertilizer studies in twelve loblolly pine plantations.[1/]

Treatment	4-year volume growth: Gross	4-year volume growth: Net
	(cu.ft/acre)	
Unthinned	1478	1197
Unthinned + N Fert	1635	1321
Fert gain	157	124
Thinned	1156	1082
Thinned + N Fert	1353	1266
Fert gain	197	184

[1/] Plantation age averaged 15.6 years with a range from 11 to 20 years; basal area in the unthinned areas averaged 156 sq.ft/acre with a range of 97 to 191 sq.ft/acre, while that in the thinned areas averaged 97 sq.ft/acre with a range of 80 to 120 sq.ft/acre. Thinning was done selectively from below. Fertilizer applied at 150 lbs. N/acre.

Nitrogen-fertilization technology has undoubtedly now reached the point where operational N fertilization can realistically be included among silvicultural options available to forest managers. However, the technology is still in a very early development stage. Refinements in predictive techniques, methods and frequency of application and an improved understanding of interactions with other silvicultural operations and long-term residual effects could further enhance its value as a silvicultural tool.

SILVICULTURAL IMPLICATIONS

Many of the major timber producing areas in the world, including the Southern United States, are facing a timber supply problem due to an imbalance in age and size classes (Zobel, 1980). The problem is associated with an abundance of young sub-merchantable plantations, a rapidly declining "old-growth" resource and an inadequate acreage of intermediate age (size) timber. The general responsiveness of loblolly pine plantations in the South to N fertilization offers a number of opportunities for reducing the impact of this imbalance on both fiber supply and material suitable for solid wood products.

Fiber Supply

Early utilization of young stands, usually by partial cutting (thinning), is a possible way of reducing the age-gap problem. However, as thinning usually reduces the amount of fiber produced per acre over normal loblolly pine rotation lengths (25-35 years), critics point out that thinning may serve only to delay the problem.

Nitrogen fertilization provides two major opportunities for reducing the age-gap problem.

1. Fertilization of young stands 5 to 7 years prior to thinning, when basal area is in the optimum range of response, would enable either earlier thinning or greater volume removal at a predetermined thinning age.

2. Fertilization of thinned stands increases the rate of growth and acts to offset the impact of growing stock removal on fiber production. Our data (table 4) show that average net periodic volume growth in fertilized and thinned stands exceeded that in unthinned stands.

Assuming no selection for responsiveness to N fertilization, the average response from N fertilization (150 lbs N/acre) of a young plantation with 60-80 sq.ft/acre of basal area would be approximately 3 cords per acre. We anticipate a response of similar magnitude would be obtained from refertilization following thinning. There is thus a potential, under such a silvicultural regime, for increasing the fiber supply from loblolly pine plantations by an average of 6 cords per acre over a rotation.

Size Class Distribution

Many of the options available for accentuating growth on individual stems—use of genetically improved stock, wide spacing at planting, intensiv site preparation—are long term in nature and thus of little use in resolving the immediate size-gap problem. Thinning is the technique most frequentl used to provide relatively short-term exploitable gains in individual stem growth. Nitrogen fertilization can also be considered among the options for providing relatively short-term improvements i the supply of larger-sized timber. In this respec fertilization can be exploited under a number of circumstances.

1. Nitrogen fertilization in conjunction wit thinning not only provides more volume gain than fertilization of unthinned stands (table 4), but this volume gain goes onto fewer, larger stems. Many stands which are commercially thinnable by today's standards of minimum extraction volumes and average diameters are, due to close planting, overstocked. In such stands the response to thinning can be minimal due to either severe crown suppression or because the residual crop componen has already established dominance. Our data (Ballard *et al*. 1980) would tend to indicate that fertilization of such stands after thinning will produce a response even though there is no respon to thinning per se or to fertilization of the unthinned stand.

2. Many intermediate and older age pine sta in the South are so grossly overstocked, that not only will there be little response to thinning but thinning places such stands in jeopardy from ice snow, and wind damage. The development of these stands to timber of merchantable size is slow. experience from fertilizing such stands shows th fertilization can produce a quite pronounced shi in diameter class distribution. In a case study was shown that an overstocked stand which showed net gain in volume from fertilization increased significantly in value due to a stimulation in growth of larger trees at the expense of smaller trees (Rogers 1978). Nitrogen fertilization off an opportunity to speed up the development of ov stocked stands into a merchantable condition.

By way of conclusion it is emphasized that fertilization of loblolly pine stands is not an obligatory management practice—in most cases st will grow and remain healthy without it. Howeve does offer an investment opportunity to produce fiber and to help resolve some supply problems.

LITERATURE CITED

Ballard, R. 1980. The means to excellence in tomorrow's plantations—through nutrient amen ment. In Forest Plantations: the shape o the future. First Weyerhaeuser Science Symposium, Tacoma, WA.

Ballard, R., H.W. Duzan, Jr., and M.B. Kane. 1 Thinning and fertilization of loblolly pine plantations. Paper presented at Southern Silvicultural Research Conference, Atlanta, November 6-7, 1980.

allard, R. 1981a. Optimum nitrogen rates for fertilization of loblolly pine plantations. South. J. Appl. For. 5: (in press).

allard, R. 1981b. Comparison of urea and ammonium nitrate as nitrogen fertilizer sources for southern pine plantations. South. J. Appl. For. 5: (in press).

engtson, G. W. 1976. Outlook for improved fertilizers and technology in silviculture. p. 88-98. In W. E. Balmer (ed.) Proc. Sixth Southern Forest Soils Workshop. USDA For. Serv. Southeast Area, State and Priv. For., Charleston, S.C.

engtson, G. W. 1979. Forest fertilization in the United States: progress and outlook. J. For. 77: 222-229.

uzan, H. W., Jr. and H. L. Allen. 1980. Estimating fertilizer response in site-prepared loblolly pine plantations using basal area and site index. Paper presented at Southern Silvicultural Research Conference, Atlanta, November 6-7, 1980.

uzan, H. W. Jr., H. Lee Allen, and R. Ballard. 1981. Predicting fertilizer response in established loblolly pine plantations with basal area and site index. South. J. Appl. For. 5: (in press).

aines, L. W., S. G. Haines, and V. H. Allen, Jr. 1976. Fertilizing established loblolly pine stands. p. 57-77. In W. E. Balmer (ed.). Proc. Sixth Southern Forest Soils Workshop. USDA For. Serv. Southeastern Area, State and Priv. For. Charleston, S.C.

ane, M. B. 1980. Fertilization of juvenile loblolly pine plantations: impacts on fusiform rust incidence. Paper presented at Southern Silvicultural Research Conference, Atlanta, November 6-7, 1980.

iller, R. E. and R. D. Fight. 1979. Fertilizing Douglas-fir forest. USDA For. Serv. Gen. Tech. Rep. PNW-83, 29 p.

ritchett, W. L. and W. H. Smith. 1974. Management of wet savanna forest soils for pine production. Univ. FL Agric. Expt. Sta. Tech. Bull. 762. 22 p.

ogers, P. H. 1978. The impact of fertilization on the growth and development of loblolly pine plantations. M.S. thesis. N. C. State University.

obel, B. J. 1980. Imbalance in the World's conifer timber supply. Tappi 63: 95-98.

UNDERSTORY BIOMASS FOR ENERGY FUEL[1]

Timothy T. Ku, James B. Baker, Charles R. Blinn
and Richard A. Williams[2]

Abstract.--A cooperative study funded by the Department of Energy was initiated in 1979 to evaluate the potential use of understory vegetation in uneven-aged southern pine forests as an energy source. Objectives are to characterize understory vegetation, determine its recovery rate from harvest and impact of harvests on site. Preliminary results indicate an average yield of 24.41 T/ha.

INTRODUCTION

The world wide demand on energy resources has resulted in accelerated research activities in renewable energy technologies including bomass energy sources. The vast area of commercial timberlands in southern United States in conjunction with its favorable environmental and socio-economical conditions provide the region with an ideal setting for investigating renewable energy resources from forest biomass.

In order to increase timber production, considerable effort has been expended to reduce competition from the unmerchantable and often unwanted understory vegetation. In view of the increasing demand on energy, the use of this renewable understory vegetation as a possible source of fuel suddenly becomes highly appealing, and a cooperative study between the Department of Forestry, University of Arkansas at Monticello, the USDA-Forest Service and Georgia-Pacific Corporation was initiated and funded by the Department of Energy in 1979.

GOALS AND OBJECTIVES

A systematic approach to the problem of using understory biomass as an energy source would include:

(1) characterization and feasibility of the resource,
(2) harvest and transport of the resource,
(3) conversion and utilization of the resource,
(4) long term effect of periodic harvests of the resource on site quality.

Due to energy shortages within the last several years, many forest industries have resorted to solid fuel boilers and generating systems in their physical plants. These plants are currentl relying, at least partially, on logging and mill residues and can be easily converted to utilize the understory biomass. Proto-type mobile harvester-chippers have been under development durin the past decade to be more efficient in harvestin and collecting the small trees and logging residu for fiber. Such systems can easily be adapted to collect and transport the understory biomass to concentration locations. These developments wil eventually solve phases (2) and (3) of the probl

This study concentrates primarily on phase (1) and to a very limited extent, obtain baselin information relating to long term impact in phas (4). If understory vegetation is a feasible ener resource which can be harvested periodically, th the use of this resource would not only suppleme the increasing demand on energy fuel but would al increase the growth of overstory crop trees, les en the need for brush control, and reduce site preparation and timber stand improvement costs.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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Table 1.--Understory Biomass (T/ha) by Site Classes

GOOD SITE				POOR SITE			
Pine		Pine-Hardwood		Pine		Pine-Hardwood	
High Density	Low Density	High Density	Low Density	High Density	Low Density	High Density	Low Density
SUMMER HARVEST							
32.84	26.34	10.29	26.70	48.26	20.49	20.49	50.42
19.23	9.21	15.31	38.38	25.89	47.21	18.43	18.38
19.64	19.70	22.73	20.44	34.84	34.81	29.16	16.99
23.90	18.43	16.12	28.51	36.34	34.16	22.69	28.60
21.16		22.33		35.26		25.65	
21.74*				30.46*			
26.12							
WINTER HARVEST							
22.42	12.76	11.81	29.16	50.93	13.76	10.13	31.99
20.16	14.59	18.70	18.18	21.92	31.00	14.93	23.25
30.40	16.59	28.18	25.62	28.36	23.99	13.38	32.55
24.32	14.64	19.57	24.32	33.74	22.91	12.82	29.25
19.48		21.95		28.34		21.03	
20.71				24.68			
22.69							
AVERAGE							
27.62	19.55	11.05	27.93	49.61	17.13	15.31	41.20
19.70	11.90	17.01	28.27	23.92	39.10	16.68	20.83
25.02	18.16	25.47	23.02	31.59	29.41	21.27	24.77
24.12	16.54	17.84	26.41	35.04	28.56	17.75	28.94
20.33		22.13		31.81		23.36	
21.22*				27.60*			
24.41							

*P < 0.10

The short-term objectives of this study is to characterize and quantify the understory biomass in uneven-aged, natural, southern pine stands in south Arkansas and north Louisiana. Long term objectives are to determine (1) the recovery rate of the understory biomass after harvest and (2) the effects of periodic harvests of understory biomass on site quality.

METHODS

Forty 0.2 hectare main plots from a factorial design with 3 replications of two forest types--pine and pine-hardwood, two stand density classes --high and low, and two site classes--good and poor was established in a 14-county area in south Arkansas and north Louisiana. During 1979-80, three replications of 24 plots were established; the remaining 2 replications of 16 plots were established in 1980-81. This paper will report the preliminary results from the 24 plots established in 1979-80. Within each main plot, all woody vegetation less than 14 cm dbh was inventoried from 18, 3.05M x 3.05M subplots. Nine subplots were harvested and chipped in late summer during full foliage and nine in winter.

Fresh weight of the chipped material from each subplot was obtained in the field. Subsamples were subsequently taken and dried at 70°C in a walk-in kiln. After drying, weighing, and determining plot dry weights, the subsamples were further pulverized in a Wiley mill and used for chemical analysis of N, P, K, Ca and Mg contents. These nutrient data are used to quantify nutrient removal from harvest.

Soil samples were collected immediately after each harvest at 7.5 and 15 cm depths from each subplot. Nutrient contents (N, P, K, Ca, Mg) will be analyzed and used with biomass nutrient data to correlate the impact of periodic harvest on nutrient reserves.

RESULTS AND DISCUSSION

Preliminary results derived from quantitative data obtained from 24 plots at the end of the first year indicated the following significant findings:

Understory Biomass Production

The average understory biomass across all 8 stand-and-site conditions was 24.41 ± 11.37 dry metric tons per hectare (T/ha) with a range of 10.13 to 50.93 T/ha (Table 1). At a conservative guess of a 10-year harvesting cycle, this chippable understory biomass would amount to nearly 2.5 T/ha/yr., which is above the commercially operable quantity for some industries under present standards.

Although the average summer harvest of 26.12 T/ha was slightly higher than the winter average of 22.69 T/ha as one would expect, analysis of variance indicated this difference was not statistically significant. This is probably due to the high variability in composition, density and site conditions among plots, and to a lesser degree, the presence of conifers and broadleaf evergreens.

Poor sites produced more understory biomass (27.60 T/ha) than good sites (21.22 T/ha) ($P<0.10$) for the average of two harvest (Table 1). Yields from the Summer harvest on poor sites was also significantly ($P<0.10$) greater. The higher understory biomass obtained from poor sites may possib be explained by the fact that more large understo stems (5 to 12.5 cm dbh) occupied poor sites than good sites (Table 2). This resulted from either past management practices and/or less shading by overstory trees. There are generally smaller numbers of large overstory trees on poor sites,perha reflecting the principle of site productivity.

Table 2.--Number of Stems by Size and Site Classe

	DBH	Good Sites	Poor Sites
	(cm)	------ Stems/ha	-------
Understory			
	5.0	1863	2143
	12.5	204	304
Subtotal		2067	2447
Overstory	20.0	116	165
	27.5	66	65
	35.0	39	36
	42.5	23	16
	50.0	12	5
	57.5	2	2
Subtotal		258	289
Total		2325	2736

Understory Biomass Composition

A Dominance-Index was derived to rank the understory biomass components by using a model:

$$DI = 1.66667 + 0.04510\ \Sigma(Di) + 0.04336\ \Sigma(Di^2)$$

where N is the number of stems for a given spec Di is the dbh of stem i for a given species, al on a per unit area basis. The model was slight modified from Chisman and Schumacher (1940).[3/]

Based on the mean Dominance-Index, the 10 most dominant understory woody species in desc ing order are: red oaks, red maple, winged el dogwood, sweetgum, pines, white oaks, French m berry, blackgum, and hickories. Hopefully, so form of a Dominance-Weight-Index may be develo so that the index will correlate with understo biomass of a stand.

[3/] Chisman, H. H., and F. X. Schumacher. 1 On the tree-area ratio and certain of its appli cations. Jour. For. 38:311-317.

Table 3.--Biomass and Nutrient Contents in Understory Vegetation (Kg/ha) by Site Classes-Summer Harvest.

Item	Good Site	Poor Site	Mean
Biomass	20,740*	30,460*	25,600
N	90.6**	109.8**	100.2
P	11.9*	12.6*	12.2
K	64.9	78.1	71.5
Ca	138.7	169.6	154.2
Mg	14.5	18.6	16.6

** $P < 0.05$
* $P < 0.10$

trient Content in the Understory Biomass

The 216 biomass samples collected from the mmer harvest (9 subplots in each of 24 main plots) re analyzed for N, P, K, Ca and Mg contents. e mean nutrient concentrations (%) of all samples were: N, 0.439; P, 0.059; K, 0.323; Ca, 0.688, and Mg; 0.081. Average nutrient removal from all summer harvested plots in Kg/ha were: N, 100.2; P, 12.2; K, 71.5; Ca, 154.1 and Mg, 16.5. Analysis of variance indicated the nutrient removal was significantly higher in nitrogen ($P<0.05$) and phosphorus ($P<0.10$) from poor sites than from good sites (Table 3), primarily a reflection of biomass differentials. Further analysis will be pursued when data from summer- and winter-harvest of all plots becomes available.

CONCLUSION

Preliminary analysis of available data indicates there is a sufficient amount of understory woody biomass in natural, southern pine forests that can be possibly harvested for energy or even fiber use. However, the recovery time required between harvests must be determined to assess biomass productivity (T/ha/yr). The nutrient concentrations of the understory biomass and the soil are also needed to quantify nutrient removal from harvest and to estimate changes of nutrient reserve from repeated harvests.

If periodic harvests of understory biomass becomes a reality, in addition to providing a renewable energy resource the harvests will also provide an inexpensive silvicultural treatment for controlling competing hardwoods in pine stands.

INVENTORYING WINDROWED LOGGING RESIDUES[1]

W. Henry McNab[2]

Abstract.--A set of user-oriented equations developed from data collected in the Georgia Piedmont allows estimation of the volume and weight of windrowed logging residues. Easily measured features of the windrows required in the prediction equations are: (1) height, (2) half-width, and (3) average diameter of pieces larger than 3 inches.

INTRODUCTION

Logging residues--entire unmerchantable trees as well as unutilized portions of harvested trees--are often windrowed during site preparation for tree planting in the South. With prices of all fuels rising, organizations that can use wood chips for fuel are beginning to show interest in logging residues (Phillips 1979). The volumes of wood involved can be quite large, particularly on pine-hardwood sites, where many low-quality hardwoods are usually left when a pine stand is harvested (Welch 1980).

Utilization of this material for fuel depends in part upon the ability to estimate the amount and type of material present. I have developed a technique that may be satisfactory on windrowed sites in the Piedmont. This paper has three purposes:

(1) to review the development of the technique,

(2) to present a method for stratified sampling of the windrows on large tracts, and

(3) to demonstrate the system.

DEVELOPMENT OF INVENTORY METHOD

Field Study Sites

Field data were collected from three clearcut pine-hardwood tracts on the Oconee National Forest in the Lower Piedmont of Georgia; all three had been sheared and windrowed after logging. The tracts were on upland sites with gently rolling terrain and predominantly sandy clay soils, eroded from earlier agricultural cropping. The harvested timber stand had a total basal area of about 85 ft^2/ac and consisted primarily of mature loblolly and shortleaf pine sawtimber, with lesser amounts of pine pulpwood. A significant portion of the pine stands consisted of various upland hardwood species including southern red oak, elm, sweetgum, and hickory. Even though many of these hardwoods were larger than 8 inches d.b.h., they were of poor quality with no readily available market. These standing hardwoods had to be removed to regenerate pine.

The sites were prepared by a single local contractor during the late fall and early winter of 1976-77. The residual hardwoods were sheared near ground level with a sharp serrated blade mounted on the front of a crawler tractor. The blade was kept high enough to avoid uprooting stumps and to reduce soil disturbance. After shearing, logging residues and sheared trees were pushed into long piles, or windrows, which follow the land contour. During the spring of 1977, the windrows were studied to determine relationships that could be used to predict the volume and weight of woody material.

Each area was sampled in a systematic manne Two categories of data, describing either the physical appearance or the biomass contents of th windrow, were collected at about 200-foot interv along the windrows. At each of the 54 sample points, the following were recorded:

(1) Height of windrow to the predominantly solid surface formed by 3-inch and larg residues.

(2) Half-width--distance from windrow edge windrow apex.

(3) Mean diameter of residues larger than 3 inches in diameter that were visible on the windrow surface.

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(4) Proportions of the residues that were (a) softwoods, (b) soft hardwoods, and (c) hard hardwoods.

A complex and time-consuming research proce- re was required to determine the actual contents the windrow at each sample point. A transect rough the windrow was formed by rods, which were serted through the residues to the soil surface various points where the windrow shape changed. e rods subdivided the windrow into a number of apezoidal segments, with the groundline and the ndrow surface forming two nonparallel ends. The rface profile of the undisturbed windrow was rked on each of the rods and the cross-sectional ea determined by summing the trapezoids. A path out 1 foot wide was then cut through the windrow ong the transect.

On both sides of this path, each piece of posed wood was counted and tallied by diameter ass if its diameter was less than 3 inches, or asured if its diameter was greater than 3 inches. pth of displaced soil included in the windrow s noted. Data were collected from a total of sample points and 33 different windrows. Also, ilar data were collected from 10 other sample nts for testing the prediction equations that ld be developed. The field data are summarized table 1.

le 1.--Mean physical characteristics of windrows n three Oconee National Forest clearcut tracts sed in development of biomass inventory method

ct	Windrow		Cross-sectional area	Wood ratio
	Height	Width		
	- - -*Feet*- - -		- - -*Feet*^{2}- -	
	3.4	6.7	24.4	0.17
	3.9	10.6	29.8	0.15
	3.3	9.3	23.4	0.19

Data Analysis

The data were analyzed to determine if a pre- tion equation could be developed to estimate the portion of the windrow cross-sectional area occu- d by solid wood. This dependent variable, re- red to as the wood ratio, was calculated as:

$$\text{Wood ratio} = \frac{\text{area of wood (ft}^2\text{)}}{\text{area of windrow (ft}^2\text{)}} \qquad (1)$$

Th independent variables included in the analysis e:

(1) Mean windrow height (feet)
(2) Mean windrow width (feet)
(3) Windrow cross-sectional area (feet^2)
(4) Number of small residue pieces (1/4 to 1 inch in diameter)
(5) Number of medium residue pieces (1 to 3 inches in diameter)
(6) Number of large residue pieces (3 inches and larger in diameter)
(7) Average diameter of large residue pieces over 3 inches in diameter
(8) Total count of all intercepted residue pieces (number)

Combination of the variables, including various transformations, were used to fit a multivariate equation to the field data.

$$Y_{wr} = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_n x_n + E \qquad (2)$$

where: Y_{wr} = wood ratio

b_0, b_1, b_2, b_n are constants

x_1, x_2, x_n are independent variables

E = experimental error

The initial analysis of the data produced a complex 7-variable equation that included several variables related to size and number of large residues measured in the windrow's interior. It was apparent that this equation would not be practical for inventories. Also, I hypothesized that a measure of the number of residue pieces would not be required since dimensions of the windrow could be interpreted as a function of residue number and sizes.

A second analysis was made based only on those variables that could be evaluated easily and quickly by inspection at the windrow sample point. These included: (1) windrow height (feet), (2) windrow width (feet), (3) windrow cross-sectional area (feet), and (4) mean diameter of large residues (inches), plus various combinations and transformations of these variables.

Analysis of this data set resulted in a prediction equation requiring only two variables, with only a slightly greater standard error than the initial 7-variable equation. This equation, which has an R^2 of 0.88 is:

$$\text{Wood ratio} = (0.635 + 0.251/H - 1.625/D)^2 \qquad (3)$$

where: H = windrow height (feet)
D = mean diameter of visible residues larger than 3 inches in diameter

In a separate analysis, I determined that the size of residues visible on the windrow surface is closely related to the size of all residues in the windrow. Therefore, D is easy to determine.

The accuracy of Equation 3 in predicting wood ratio was confirmed using data collected from the 10 additional sample points that were not included in the regression analysis. The results are shown in figure 1, plotted around the line of perfect correlation. Since this equation estimates only the proportion of wood present in the windrow cross section at the sample point, a means of determining windrow area at the sample point was required before residue area could be calculated.

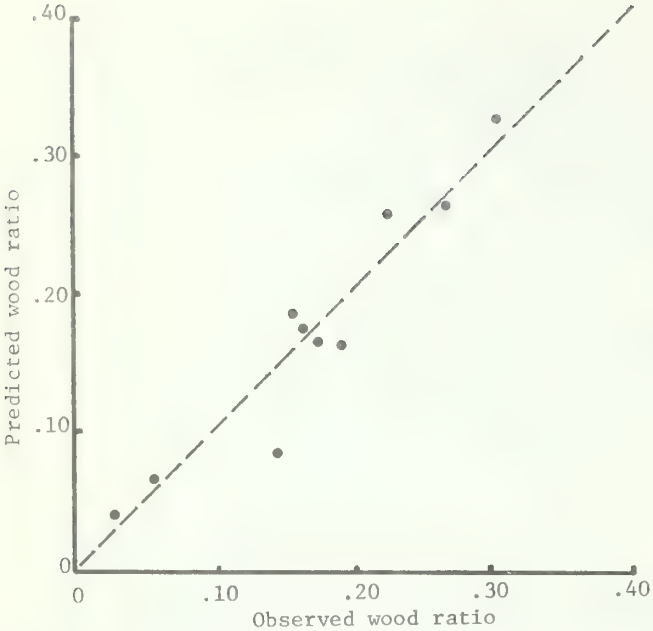

Figure 1.--Relationship of predicted wood ratio to observed wood ratio using data collected from 10 windrow sample points on the Oconee National Forest.

Further analysis of the field data revealed that cross-sectional area of a windrow is fairly easy to estimate with reasonable precision. Acceptable estimates of windrow area were calculated by multiplying height by half-width--the distance from the near edge of the windrow to its highest point (fig. 2). Half-width is easier to measure than full-width because one person can make the measurements without crossing the windrow. As shown in figure 3, estimated area for the 54 sample points was closely related to measured area:

$$\text{MA (ft}^2\text{)} = 3.39 + 1.19 \text{ (EA)} \qquad (4)$$

where: MA is measured windrow cross-sectional area and
EA is the estimated area (ft^2).

Equation 4 shows that area was underestimated by about 19 percent, but the R^2 of .96 indicates that the underestimates were fairly consistent. Residue weight per foot-length of windrow was determined using wood density and results from Equations 1 and 3 in the following relationship:

$$\text{Residue wt (lb/ft)} = \text{Windrow area (ft}^2\text{)} \times \text{Wood density (lb/ft}^3\text{)} \times \text{Wood ratio} \times 1 \text{ Foot} \qquad (5)$$

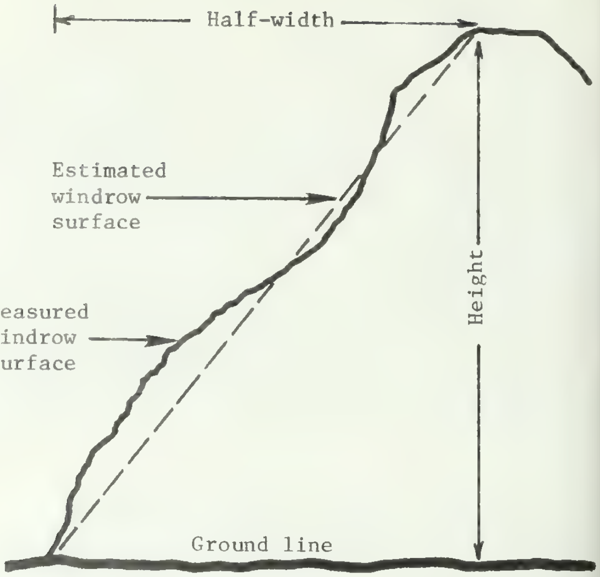

Figure 2.--Windrow cross section showing height an half-width measurements used to calculate cross-sectional area as partial inputs for estimating biomass.

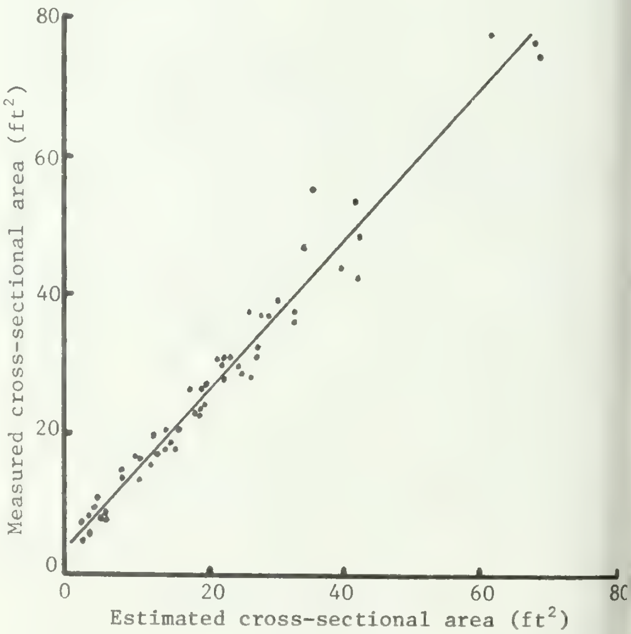

Figure 3.--Relationship of measured windrow cross-sectional area to estimated windrow cross sectional area determined from 54 sample points on the Oconee National Forest.

The result of this relationship is the estimated residue weight contained in 1 linear foot of windrow, for an average sample point. Published values of wood density from the Wood Handbook (U.S. Forest Products Laboratory 1974) may be used, and are presented by species on a basis of 12 percent moisture content. For ease in collecting field data, species may be grouped in classes of softwoods and soft and hard hardwoods. For even more simplicity, an overall mean value of 35 lb/ft wood density may be assumed for windrowed residue on pine-hardwood sites in the Piedmont.

Table 2.--Characteristics of windrows and logging residues on middle and upper slope positions of an industrially owned clearcut tract in the Lower Piedmont of Georgia

Subsample location	Points sampled	Windrow			Mean residue diameter	Residues	
		Spacing	Height	Half-width		Windrowed	Scattered
	Number	*Feet*			*Inch*	*Tons/ac*	
1	12	163	4.1	5.6	4.6	16.9	5.1
2	9	172	4.8	6.0	4.1	14.1	2.8
3	14	193	5.2	6.1	4.2	14.3	2.5
4	4	93	4.0	5.8	4.0	21.6	3.9
5	10	104	4.1	5.3	4.5	24.0	2.6

Total biomass on the tract is estimated by ltiplying the residue weight per linear foot by al length of windrows. On small tracts, it is rhaps easiest to walk along and measure the gth of all windrows, while collecting the neces- ry data from at least 30 sample points. However, s method is time consuming and may be impractical larger tracts.

SUBSAMPLING WINDROWS ON LARGE TRACTS

In sampling large tracts, it is only necessary collect data from representative segments of drows, and to determine the mean spacing between drows. In the Piedmont, windrow spacing may ge from 150 to 250 feet, depending on terrain amount of residues.

Windrow spacing, in some instances, may not uniform and individual measurements of windrow cing are needed. Agricultural terraces, gullies, wood roads, for example, influence spacing. ticular attention to individual measurement of idue accumulation area should be made when win- ws appear larger or smaller than the average e normally seen on the tract.

Combining the windrow spacing with the length windrow sampled provides an estimate of the area pled. The area sampled, combined with the total imated residues on that area, allows calculation the weight per unit area of windrowed material, ch reduces to the relationship:

$$\text{Windrow residue wt (tons/ac)} = \frac{\text{Residue wt (lb/ft)} \times 21.78}{\text{Windrow spacing (ft)}} \qquad (6)$$

ractice, a convenient method of collecting d data, using this subsampling procedure, in- es measuring segments of two adjacent windrows, "U" pattern, which returns the observer to starting point. The observer walks along a lrow for perhaps 1,000 feet, stopping to collect le data at about 200-foot intervals. He then s to the adjacent windrow, records the distance collects windrow data in the opposite direction the same distance. Windrow spacing is again rmined as the observer returns to the starting t at the first windrow. Other variations of basic sampling scheme are obvious.

Similar windrow subsample data should be col- ed over the entire tract. Subsampling should ystematic and stratified so that ridgetops with t residues and lower slopes with larger amounts ardwoods are proportionally represented.

EXAMPLE OF APPLICATION OF INVENTORY TECHNIQUE

Logging residues on a clearcut and windrowed industrially-owned tract in the Lower Piedmont of Georgia were inventoried to estimate the biomass remaining after a commercial harvest. Characteristics of the timber stand before harvest are unknown, but about 10 cords of pine and 6 cords of hardwood per acre were harvested.

The tract was similar to the National Forest sites where the biomass estimation technique was developed. Here, however, site preparation consisted of roller chopping, followed by windrowing, instead of KG blading and windrowing. The windrows were similar in appearance to the National Forest site; relatively low, narrow, and with very little soil. A small amount of scattered residues remained between the windrows and helped retard water movement and soil erosion on the cleared site. The large size of the tract, 165 acres, precluded sampling all windrows; 5 subareas were sampled instead. Results of the inventory are summarized in table 2.

About 23 tons of biomass were harvested from this tract. Even with the exceptionally high degree of hardwood utilization practiced by this industrial owner, about 21 tons of the original biomass remain, of which 18 tons are in windrows. Thus, efficiency of total biomass utilization for conventional pulpwood products was about 50 percent. If markets had been available at the time of harvest, whole tree chipping of the larger residual hardwoods for fuelwood could have increased utilization perhaps by another 25 percent. Ideally, evaluation of the potential fuelwood yield should be made during the preharvest cruise, using available prediction equations (Phillips and Saucier 1979).

LITERATURE CITED

Phillips, Douglas R.
1979. Forest residue: A significant source of energy. Sou. Lumberman 239(2967):101-102, 106.

Phillips, D. R., and J. R. Saucier.
1979. A test of prediction equations for estimating hardwood understory and total stand biomass. Ga. For. Res. Pap. No. 7. Ga. For. Comm., Macon, GA.

U.S. Forest Products Laboratory.
1974. Wood Handbook: Wood as an engineering material. USDA Agr. Handb. 72, rev.

Welch, Richard L.
1980. Living residues in the South Atlantic States. Forest Prod. J. 30(6):37-29.

IMPACT OF NANTUCKET PINE TIP MOTH ATTACK ON YOUNG LOBLOLLY PINE BIOMASS[1]

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Abstract.--In a 10-year-old loblolly plantation in Maryland, measurements were made to estimate above-ground biomass of trees which had early protection from Nantucket pine tip moth attack, and biomass equations were developed. A high correlation was found between volume and dry weight. The mean volume (outside bark) for treated trees was estimated as 2.29 ± 0.9 ft^3/tree and for the untreated trees as 0.6 ± 0.25 ft^3/tree, indicating that protection resulted in 280% more volume. The average predicted dry weight of the protected trees was 96.81 lbs while the average predicted dry weight of unprotected trees was 33.35 lbs, i.e., 185% more dry weight in the trees protected from the tip moth. The treated trees had approximately 2X the amount of foliage (dry weight) of the control trees. The results indicate the use of biomass measurement techniques offer important advantages over previously reported methods and that tip moth losses may be larger then previously recognized.

INTRODUCTION

The Nantucket pine tip moth (*Rhyacionia frustrana* Comstock) is a well known pest of loblolly and other species of pine. Numerous studies have been conducted to estimate its impact on young pines, but the circumstances where control measures are warranted are still not well defined. In virtually all cases, the studies showed reduced growth in younger trees, but often, work was not carried beyond about age 10. Measurements tended to show less and less differences with time. It is generally concluded that the advantages of treatment for protection against tip moth (NPTM) tend to wash out or become insignificant by age 18 or 20. For example, in a southwide test, Williston and Barras (1977) showed losses at age 15 due to NPTM which would exceed 300-500 cubic feet/A if projected over a 25-year rotation. They concluded, however, that treatment was not economically justifiable using volume as a criterion.

Tip moth impact is reflected in other tree characteristics as well as height and diameter. Because tip moths destroy new green shoots, we wanted to investigate the effect of tip moth damage on crown morphology and investigate the basic question of destruction of photosynthetic capacity (Lashomb *et al*. 1978) and its outcome. In addition to growth impact, tip moth attack can cause reductions in wood and lumber quality (Hedden and Clason 1980).

The NPTM has two generations per year in th northern parts of its range and as many as six i the Coastal Plain of the southern United States. The number of tip moth generations in a particul region roughly corresponds to the number of grow cycles (flushes) for loblolly and shortleaf pin in that region. As the larvae develop, they fee downward in the newly developing shoots, then i the older shoots formed in the last growth cycl of the tree. The result of this feeding behavi is a net reduction in the potential photosynthe area of the tree.

Trees may be repeatedly attacked until the are 10-15 feet in height. At this height, loblolly pine growth phenology and shoot morpholog hange. The number of growth cycles declines to ne or two per year, and the size of the buds and hoots significantly increase in size. Apparently he trees come under less attack partly because oth emergence is out of phase with shoot growth, nd when attack does occur, the trees are better ole to tolerate the effects of attack.

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We postulated that complete tree above-ground CTag) biomass measurements would give a more omplete picture of tip moth impact than conven- ional volume estimates and provide better in- ormation for the land manager considering ontrol options. The objective of the study herefore was to evaluate the impact of NPTM on oblolly pine in terms of CTag biomass in trees hich had received tip moth control.

PROCEDURES

Study Site

The trees were planted in an abandoned falfa-clover field at the USDA Agricultural search Center, Beltsville, MD. The field was vided into 36 plots 12 x 12 feet spaced approxi- tely 10 feet apart. Four species of pines-- blolly pine (*Pinus taeda* L.), Scotch pine . *sylvestris* L.), red pine (*P. resinosa* Sit.), d eastern white pine (*P. strobus* L.)--were anted randomly with respect to species on 3-foot nters within each plot. Each species was plicated four times in each plot (= 16 trees per ot). The red, white, and Scotch pine were 4-5 ar-old nursery-grown seedlings from Pennsylvania d were planted with bare roots. The loblolly nes were 2-3 year-old pot-grown trees from rginia and were planted with the rootball tact. The trees were planted in April 1971 in foot diameter by 1-foot deep holes. A soil x consisting of 50% each of peat moss with 4 nces of Osmokote^R (18-6-12 NPK)/bushel and il was packed around the roots.

The plots were divided into two groups: (1) e group of 20 containing untreated trees, and) 16 containing trees treated to prevent tip th attack. During 1971-72 the treated trees re enclosed in 50-mesh Saran screen cages ntaining three different moth densities (12, , 48 adults/cage) to investigate the effect of is variable. Less than 2% of the tips were fested, however, and this part of the experiment s discontinued in 1972. In 1973 the cages were moved before growth began and the trees were rayed with a 1% solution of dimethoate 2 weeks ter the peak moth emergence of each generation. e to the poor survival of the other species, ly the loblolly pines were treated.

In May 1980, after nine complete growing asons in the field, the dbh and the diameter the ground line of all trees was measured. ees for biomass determination and stem analysis re selected proportionally from the diameter stribution of each treatment. Of the 64 original insecticide-treated trees, nine were eliminated due to mechanical damage.

Biomass was determined for 10 trees from each treatment using the procedures slightly modified from Saucier (1979). Dead branches were a very minor component and were not included in the weights. Live branches were pooled for weighing and not stratified by diameter. Biomass equations were developed using standard regression techniques. Both wet and dry weight of each biomass component was modeled as log (weight) = a + b log (D^2H) where D is the diameter at ground line in inches and H is the total height of the tree in feet. Average volume outside bark was determined for each of the 10 insecticide-treated and untreated check trees harvested for biomass determination. Individual tree volume equations for loblolly pine developed by Smalley and Bowers (1968) were used for this purpose.

In addition to the trees sampled for biomass determination, six treated and 21 untreated trees were returned to the laboratory for stem analysis. The stems were split along the pith, and the numbers of leader disturbances (stem breaks) per foot of stem were calculated. The number of leader disturbances has proven to be a relatively good measure of tip moth infestation levels in the past (Hedden and Clason, 1980).

RESULTS AND DISCUSSION

Growth Impact

Between 1972-74 there was significantly less height increment, number of available growing tips, and total tip growth in the trees repeatedly attacked by NPTM. Annual damage was estimated by measuring total growth of uninfested shoots and dieback of each infested tip. Damage (total dieback/total growth x 100) averaged 19.6, 25.8 and 17.7%, respectively, for the 3 years (Lashomb *et al*. 1978). Essentially the destruction of the developing meristems caused shorter internodes and branches resulting in less photosynthetic area (Lashomb *et al*. 1978).

Volume Impact

The average dbh of the 55 insecticide-treated trees in this study was 5.51 in (sd = ±.88), and the average dbh of the 47 attacked trees was 3.54 in (sd = .77). The average volume for the 10 insecticide-treated trees was 2.29 ± 0.90 cubic feet (avg dbh = 5.5 ± .8 in) while the 10 untreated trees averaged 0.60 ± 0.25 cubic feet (avg dbh = 3.5 ± .7 in). Height measurements were not made of the entire stand. However, since the dbh's and standard deviations of the treated and untreated trees corresponded so closely with those of the trees whose heights were measured during biomass sampling, we concluded that these adequately reflect the volume for both larger populations of trees. These data show there was 280% more volume among the trees protected from tip moths. This reduction in volume corresponds to the difference in the number of leader disturbances due to tip moth attack. The untreated trees averaged 0.86 stem breaks per foot while the protected trees had an average of 0.25 per foot.

Biomass Impact

The data for the biomass equations and dry weight are given in table 1. The average green weight of insecticide-treated trees was 201.57 lbs while the average weight of tip moth-attacked trees was 72.95. This difference represents a 64% reduction in biomass where the trees were not protected from tip moths. The average predicted dry weight of the treated trees was 96.81 lbs while the average predicted total dry weight of the unprotected trees was 33.35 lbs. This difference is a 185% increase in total dry weight in the trees with tip moth protection.

Table 1.--Values for biomass regression equation for dry weight (pounds) for tree components by treatment. Equation form: $\ln (W) = a + b \ln (D^2H)$.[1]

Tree component	Intercept (a)	Slope (b)	R^2	$S_{y\cdot x}$
	Insecticide-treated trees			
Total tree	-2.42506	.94241	.86	.15351
Bole	-2.02282	.79920	.80	.15940
Foliage	-5.23155	1.05552	.71	.27231
Branches	-4.84749	1.12258	.83	.20845
	Untreated trees			
Total tree	-1.44521	.78662	.90	.12531
Bole	-2.44481	.82995	.81	.19856
Foliage	-0.88941	.45272	.41	.26839
Branches	-3.80566	.96776	.86	.19574

[1] W = weight in lbs, D = diameter at ground line (in) and H = total tree height (ft).

Similar biomass differences were evident for other component tree parts for the two treatments with the exceptions of the amount of the live crown which was in branches (table 2). We use the term live crown to denote the foliage and branches combined, exclusive of the bole. Among the insecticide-treated trees, 70% of the live crown was branches (dry weight) whereas the trees unprotected from tip moth had 59% of the live crown in branches (table 3).[5] Furthermore, 14% of the total biomass in the protected trees was foliage compared to 21% in the attacked trees although the protected trees had almost 2x more total foliage biomass than the unprotected trees. These differences suggest that the differences in average tree biomass will continue to increase in the future.

Table 2.--Predicted average weights for the components of 10 insecticide-treated and 10 untreated trees.

Tree component	Dry weight	
	Insecticide-treated	Untreated
	------------- lbs	------------
Total tree	96.81	33.35
Bole	49.69	16.18
Branches	33.05	10.01
Foliage	13.63	7.00

Table 3.--Adjusted dry weights in pounds for the tree component parts by treatment.

Tree no.	D[1]	H[2]	Total tree	Bole	Foliage	Branch
			Insecticide-treated			
1	8.6	25.1	123	55	20	48
2	9.4	26.1	--	--	--	--
3	9.7	26.7	118	57	17	45
4	6.9	26.5	66	40	7	19
5	8.6	25.8	141	73	19	49
6	8.2	27.3	100	52	20	27
7	8.0	21.7	73	38	8	28
8	8.8	22.4	110	61	13	36
9	5.4	22.6	42	24	6	12
10	7.5	24.3	73	37	11	25
			Untreated			
1	7.5	18.6	49	22	10	17
2	4.1	14.0	17	7	5	5
3	6.0	17.7	41	18	8	15
4	6.0	16.4	36	16	11	11
5	5.0	16.7	29	15	7	7
6	4.6	16.3	25	12	6	7
7	4.5	15.8	17	8	5	4
8	6.1	16.1	37	23	4	10
9	5.3	16.3	34	18	7	10
10	7.0	18.0	48	24	9	15

[1] D = diameter at ground line (in).

[2] H = total tree height (ft).

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[5] Data for the adjusted green weights for component tree parts corresponding to the data i table 3 have been omitted but are available from the authors on request.

The differences in biomass observed in this udy are extreme and must be interpreted with ution. The study design is atypical in many spects. The initial 3 by 3 foot spacing, screen otection of the insecticide-treated seedlings r one year, and the insecticide treatment it- lf could have had unknown, but significant fects on the results.

We feel that the observed differences prob- ly represent the largest impact from Nantucket ne tip moth that can be expected to occur. rthermore, we feel additional, better controlled periments are necessary to realistically quanti- the impact of Nantucket pine tip moth attack loblolly pine biomass. However, this study presents a starting point for future studies.

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LITERATURE CITED

den, Roy L., and Terry Clason.
980. Nantucket pine tip moth impact on loblolly pine wood and product quality. In: Forestry Research Report 1979, North Louisiana Hill Farm Experiment Station, Homer, Louisiana, pp. 57-72. LSU, Agric. Expt. Sta.

homb, J. H., A. L. Steinbauer, and L. Douglas.
978. Impact studies of Nantucket pine tip moth. Environ. Ent. 7(6):910-912.

cier, J. R.
979. Estimation of biomass production and removal. In: Proc. Impact of Intensive Harvesting on Forest Nutrient Cycling, pp. 172-189. SUNY, Coll. of Environ. Sci. & Forestry, Syracuse, N.Y.

lley, G. W., and D. R. Bower.
968. Volume tables and point-sampling factors for loblolly pines in plantations on abandoned fields in Tennessee, Alabama, and Georgia Highlands. USDA Forest Service Res. Pap. SO-32. 13 pp.

liston, H. L., and S. J. Barras.
977. Impact of tip moth injury on growth and yield of 16-year-old loblolly and shortleaf pine. USDA For. Ser. Res. Note SO-221. 6 pp.

BIOMASS AND NUTRIENT RELATIONSHIPS IN COASTAL PLAIN HARDWOODS[1]

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Abstract.--Increased emphasis on shorter rotations and greater utilization of aboveground biomass through whole-tree harvesting necessitates investigation into nutrient content and distribution in forest stands. Nutrient content information is presented for water tupelo, water oak, and black gum growing in varying site conditions. Results show that elemental concentrations decrease in the order foliage > branches > stem bark > stem wood although this trend varies somewhat with nutrient and species. Actual nutrient content occurs in the order stem wood > branches > stem bark > foliage. Whole-tree harvesting can increase biomass removal over stem harvesting by about 25% and nutrient removal by about 25-120% depending upon species, element, and season of harvest.

INTRODUCTION

Improved harvesting efficiency and product utilization have been the impetus behind increasing whole-tree harvesting or removal of all aboveground biomass. The recent growth of interest in new energy sources and the extension of harvesting into stands previously considered to be unmerchantable have been offered as reasons for the growing trend toward increasing the degree of forest utilization (Morrison and Foster 1979). Concerns have arisen that this harvesting system may lead to decreased forest productivity through soil nutrient depletion (Borman et al. 1968, Boyle et al. 1973, White 1974). Nutrients contained in standing biomass represent just one segment of the total site nutrient pool. To fully evaluate the impact of intensive harvesting on site productivity, the complete forest nutrient cycle must be considered.

Forest nutrient cycling consists of inputs, cycling within the system and outputs. In undisturbed forests, inputs are normally small but sufficient to balance outputs since nutrient losses from undisturbed forests are minimal (Haines 1978). The annual nutrient uptake by most forest species is on the same order as that of many agricultural crops, but because a major portion of the absorbed nutrients are returned to the forest floor, or translocated within the tree, relatively small amounts are retained each year in an annual accretion of biomass (Pritchett 1979). Rolfe et al. (1978) have found that in a mature Illinois oak-hickory forest 80 percent of the total site nutrient pool was in the soil, 15 percent in the above ground biomass, 4 percent in root systems and 1 percent in the forest floor litter.

The largest nutrient removal from the forest system occurs in the harvesting procedure and can result in substantial losses. The effects of timber harvesting on the nutrient cycle depends upon intensity and frequency of removals, site disturbance, and pre-harvest site conditions. Nutrients removed in wood and bark comprise only small fraction of the site's total nutrient reserves (Rolfe et al. 1978). Foliage and branches contain the largest nutrient concentrations and it is the harvesting of this material that can dramatically increase nutrient removal from the site. Conventional tree harvesting which removes only the main portions of the stem leaves large quantities of nutrient-rich biomass on the site. In contrast, short rotation intensive culture (SRIC) systems may double normal biomass removals nd consist of a series of shorter rotations which onsiderably promotes nutrient depletion from the ite (Boyle 1975).

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An apparent need has developed for reliable stimates of stand nutrient content and distribuion for commercial species. White (1974) states he importance of foresters establishing the rate nd amounts of nutrients removed from sites by RIC systems as well as whole-tree harvesting of lder stands. Such data is being generated hrough an ongoing project by the North Carolina tate University, Hardwood Research Cooperative, nd the U. S. Forest Service, Southeastern Forest xperiment Station at Athens, Georgia.

A comprehensive and detailed study was deigned for mixed southern hardwoods in the Coastal lain, Piedmont and Southern Appalachian Mountains. he Southern Hardwood Forest Resource represents bout forty percent of the total commercial forest and and contains about fifty-one percent of all orest growing stock making it potentially the egion's most important resource. The study interates area plot sampling and sampling individual rees adjacent to area plots. Accurate stand data re documented as well as supplementary informaon necessary to complete needed diameter classes the major species found on the area plots.

The initial phase of the study is being concted in the Gulf and Atlantic Coastal Plains. ven-aged stands of mixed hardwoods are being mpled to quantify biomass, energy yields, nutrit content and distribution, and other subordinate getation and soils information. It is anticipat that this information will form a comprehensive omass, nutrient and energy content data base for e Southern Hardwood Forest.

METHODS

Twenty-four circular one-tenth acre (.04 ha) ots are being distributed in mixed, even-aged rdwood stands in the Atlantic and Gulf Coastal ains. Two replications each of four age class- (10, 20, 40 and 60 years) are being located in ree site types: (1) bottomland--floodplain areas jacent to stream drainages, predominantly of am or silt loam soils, (2) wet flats--broad, terstream areas with poorly-drained nonalluvial ils, and (3) swamps--including peat and muck amp interstream areas characterized by heavy ganic matter accumulation and very poor drainage. ots are randomly located within stands to comete this site type-age class matrix. These sites pport stands which make up the largest proportion commercial hardwoods in the Coastal Plain. esently, 19 plots have been installed (Table 1).

Table 1. Distribution of 19[1] one-tenth-acre (.04 ha) Coastal Plain biomass plots established by the N. C. State Hardwood Research Cooperative during 1978-79.

Age Class	Site Type, Location, Cooperator and Plot Number		
	Bottomland	Wet Flat	Swamp
10	(16) Sumter Co., AL American Can Co. (18) Bertie Co., NC Georgia-Pacific Corp.	(20) Duvall Co., FL Container Corp.	
20	(10) Warren Co., MS International Paper Co. (13) Sumter Co., AL American Can Co.	(19) Taylor Co., FL Buckeye Cellulose Corp.	(15) Nassau Co., FL Rayonier, Inc.
40	(2) Dallas Co., AL Hammermill Paper Co. (3) Southampton Co., VA Union Camp Corp. (1) Marion Co., SC International Paper Co.	(9) Washington Co., AL Scott Paper Co. (7) Taylor Co., FL Buckeye Cellulose Corp.	(5) Craven Co., NC Weyerhaeuser Co. (4) Hertford Co., NC Union Camp Corp.
60	(11) Wayne Co., MS Scott Paper Co. (14) Escambia Co., FL St. Regis Paper Co.	(6) Craven Co., NC Weyerhaeuser Co.	(12) George Co., MS Masonite Corp. (8) Taylor Co., FL Buckeye Cellulose Corp.

1/ Plot 17 was established on the Piedmont.

Soil, litter, understory vegetation, sapling ees and pulpwood and sawtimber trees are being mpled. This paper is limited to the sawtimber d pulpwood trees. Pulpwood trees 5.0-10.9 inches 2.7-27.7 cm) and sawtimber trees > 11.0 inches 7.9 cm) in diameter on plots are felled and measured for total height and heights to various merchantable diameter outside bark (dob) limits. Disks approximately 1.5 inches (3.8 cm) thick are removed at stump height, breast height, at quarter points up the stem to a 4.0 inch (10.2 cm) dob and at 2.0 inch (5.1 cm) dob for nutrient content analysis. A maximum of three trees per species, per diameter class is used for the above determinations. Stems are cut into short sections and weighed green in the field to the nearest 0.1 pound (0.05 kg) on a 300 pound (136.1 kg) capacity portable scale. From each tree, three sample branches are cut at 2 inches dob from lower, middle and upper crown and weighed with foliage and small branches ($\leq$ 0.5 inches) intact. The foliage is removed and sample branches reweighed. Small branches ($\leq$ 0.5 inches) are removed and sample branches reweighed excluding foliage or small branches. All other branches are cut from the bole and segregated into three size classes: extra large (> 4.0 inches dob), large (2.0-4.0 inches dob), and medium (< 2.0 inches dob). One disk is taken from each category for nutrient content analysis. Individual trees of major species are sampled and processed in the same manner as those within the area plots as necessary to acquire a minimum of 3 trees/1 inch size class on a given site type.

Green weight of each disk with bark is measured to the nearest 0.1 gram and minimum and maximum dob recorded. Disks are debarked and weighed to the nearest 0.1 gram with minimum and maximum dib recorded. The disk and a representative bark subsample are dried at 60°C. Branch samples are processed in the same manner except for branches less than 0.5 inches and .5-2 inches where wood and bark are not separated. Samples are ground in a Wiley Mill fitted with a 20 mesh stainless steel screen. Total nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), and Magnesium (Mg) are measured following wet ashing; N and P are determined colorimetrically as the ammonia salicylate and phosphomolybdenum complexes respectively; K, Ca, and Mg are determined by atomic absorption spectrophotometry.

RESULTS

Nutrient data are presented for three major species: water typelo (*Nyssa aquatica* L.) from plot 4, water oak (*Quercus nigra* L.) from plots 7 and 11, and black gum (*Nyssa sylvatica* Marsh.) from plot 12 (Table 1). All plots were sampled in late summer or early autumn when nutrient concentrations have been shown to be most stable (Bowersox and Ward 1977).

Several trends occurred consistently in the nutrient concentrations in all three species (Tables 2, 3, and 4):

- Nutrient concentrations were generally higher in bark than in wood for all elements, particularly for Ca.
- The order in which nutrient concentrations occurred by component was foliage > branches > stem bark > stem wood except for Ca where the order was stem bark > branches > foliage > stem wood.
- Nutrient concentrations in bark varied less among bole positions than those in wood, except for Ca where the opposite trend occurred.
- Nutrient concentrations in stem wood generally decreased from the butt to mid-bole, then increased with bole height thereafter.
- Magnesium and P varied least of all elements with bole height in wood and bark.
- There was generally a decrease in nutrient concentration with increasing branch diameter in both branch wood and bark except in the case of Ca in branch bark where the opposite trend occurred.
- The order in which nutrients occurred in bole bark was always Ca > N > K > Mg > P.

The above trends also occurred in other bott land hardwood species growing in similar stands (Messina 1980).

Table 2. Average percent concentration of five elements by sampling position for six water tupelo trees (DBH range 5.9-19.9 inches).

			Percent Concentration		
Sampling Position	N	P	K	Ca	Mg
Leaves	1.24	.10	.60	.83	.33
Branches <.5" (wood and bark)	.37	.05	.22	.67	.11
Branches .5"-2" (wood and bark)	.22	.03	.14	.26	.05
Branches 2"-4"					
Wood	.13	.02	.10	.09	.03
Bark	.39	.03	.12	.89	.10
Branches > 4"					
Wood	.13	.02	.08	.11	.03
Bark	.32	.02	.08	1.05	.07
Stem Wood					
Butt	.12	.02	.12	.16	.05
DBH	.10	.02	.10	.20	.04
1/4 height	.10	.02	.10	.14	.04
1/2 height	.11	.02	.09	.13	.03
3/4 height	.13	.02	.10	.12	.04
4" dob	.13	.03	.10	.10	.04
2" dob	.15	.03	.13	.10	.04
Stem Bark					
Butt	.42	.03	.12	3.34	.15
DBH	.35	.03	.11	2.19	.11
1/4 height	.35	.02	.11	1.62	.11
1/2 height	.35	.02	.11	1.35	.09
3/4 height	.37	.02	.11	1.21	.10
4" dob	.38	.03	.14	1.10	.12
2" dob	.43	.03	.19	1.38	.16

Table 3. Average percent concentration of five elements by sampling position for six water oak trees (DBH range 5.5-13.9 inches).

			Percent Concentration		
Sampling Position	N	P	K	Ca	Mg
Leaves	1.38	.12	.43	1.11	.17
Branches < .5" (wood and bark)	.53	.10	.29	1.55	.11
Branches .5"-2" (wood and bark)	.41	.07	.18	.87	.06
Branches 2"-4"					
Wood	.19	.03	.24	.15	.03
Bark	.30	.02	.08	2.56	.03
Branches > 4"					
Wood	.12	.02	.26	.14	.02
Bark	.29	.02	.08	2.66	.03
Stem Wood					
Butt	.12	.01	.12	.23	.03
DBH	.11	.01	.10	.15	.02
1/4 height	.09	.01	.10	.14	.02
1/2 height	.11	.01	.15	.16	.02
3/4 height	.12	.01	.20	.16	.03
4" dob	.16	.02	.17	.16	.03
2" dob	.25	.03	.15	.15	.04
Stem Bark					
Butt	.31	.02	.08	3.43	.03
DBH	.29	.02	.09	2.80	.03
1/4 height	.28	.01	.11	3.32	.03
1/2 height	.28	.02	.09	2.99	.03
3/4 height	.27	.02	.08	2.43	.03
4" dob	.31	.02	.06	2.14	.03
2" dob	.37	.02	.07	2.06	.04

Table 4. Average percent concentration of five elements by sampling position for six black gum trees (DBH range 5.3-16.1 inches).

Sampling Position	Percent Concentration				
	N	P	K	Ca	Mg
Branches < .5" (wood and bark)	.46	.06	.22	.66	.10
Branches .5"-2" (wood and bark)	.27	.03	.13	.33	.05
Branches 2"-4"					
Wood	.11	.02	.10	.10	.03
Bark	.42	.03	.15	1.33	.12
Stem Wood					
Butt	.16	.02	.10	.14	.03
DBH	.13	.02	.08	.14	.03
1/4 height	.14	.02	.07	.11	.03
1/2 height	.15	.02	.08	.11	.03
3/4 height	.17	.03	.09	.13	.03
4" dob	.18	.03	.09	.13	.03
2" dob	.23	.04	.10	.12	.03
Stem Bark					
Butt	.54	.04	.21	3.00	.13
DBH	.52	.04	.18	2.80	.10
1/4 height	.43	.03	.15	2.36	.10
1/2 height	.38	.02	.13	1.93	.09
3/4 height	.39	.02	.15	1.80	.08
4" dob	.43	.03	.17	1.65	.11
2" dob	.47	.04	.18	1.52	.11

Water Tupelo

Nutrient concentrations followed the aforeentioned general trends (Table 2). In stem wood, ost elements showed significant differences in oncentration (P = .05 level) between butt disk nd 2-inch dob disk except K and Mg; for stem bark nly K and Ca concentration differences were sigificant. The order in which nutrients occurred n stem wood is Ca > N > K > Mg > P; for foliage he trend is N > Ca > K > Mg > P.

Water Oak

Elemental concentration trends (Table 3) were imilar to those in water tupelo. An exception as the order in which nutrients occurred in stem ood: Ca > K > N > Mg > P. In stem wood, only and P showed significant differences in concenration between butt and 2-inch dob disk; in stem ark, it was N and Ca concentrations that differed ignificantly.

Black Gum

Nutrient concentration trends (Table 4) reembled those cited for all other species. The ierarchy of nutrient concentration for stem wood as N > Ca > K > Mg > P. In stem wood, only N nd P showed significant differences in concentraion between butt and 2-inch dob disk; in stem ark, only Ca showed significant differences beween both positions. Foliage data is lacking for lack gum because the plot on which it occurred as sampled following leaf abscission.

Tables 2, 3, and 4 show that whole-tree harvesting will remove tree components containing the highest nutrient concentrations rather than leaving them as slash. To evaluate the additional nutrient removals from whole-tree harvesting, nutrient concentrations must be coupled with biomass data to determine actual nutrient weights contained in each tree component.

Table 5 illustrates relationships between biomass and nutrient content in water tupelo.

Table 5. Dry weight and nutrient content of water tupelo expressed as a percentage of whole-tree totals.

Component	Wt.	N	P	K	Ca	Mg
Bole Wood	75.6	51.3	58.6	67.2	37.4	57.8
Bole Bark	8.3	17.1	10.3	7.8	44.3	15.3
Bole Sub-total*	83.9	68.4	68.9	75.0	81.7	73.1
Top Wood	2.6	2.7	5.3	3.3	0.8	2.3
Top Bark	0.5	4.0	2.7	2.3	4.0	3.6
Branches	11.5	15.3	16.5	12.4	10.1	12.4
Foliage	1.5	9.6	6.6	7.0	3.4	8.6
Top Sub-total	16.1	31.6	31.1	25.0	18.3	26.9

* Stump to 4-inches diameter-outside-bark.

These data can be useful when assessing the extent of nutrient removal associated with harvesting systems. A harvest of total aboveground material will increase biomass removal by approximately 19% over a conventional bole harvest to a four-inch top. However, such a harvest would increase nutrient removals by the following percentages; N, 46; P, 45; K, 33; Ca, 22; and Mg, 37. It is interesting to note that although the bole wood weight is nearly nine times that of bole bark, the bark contains substantially more Ca than the bole wood owing to the comparatively high Ca concentrations in bark tissue. The elements least affected by increasing biomass removal are potassium and calcium due to the large amounts of potassium in bole wood and calcium in bole bark.

The additional nutrient depletion effect of whole-tree harvesting of water oak is relatively greater than that for water tupelo (Table 6).

Table 6. Dry weight and nutrient content of water oak expressed as percentage of aboveground totals

Component	Wt.	N	P	K	Ca	Mg
Bole Wood	68.2	31.8	28.6	62.7	13.1	40.8
Bole Bark	10.9	13.7	7.5	7.1	46.1	10.1
Bole Sub-total*	79.1	45.5	36.1	69.8	59.2	50.9
Top Wood	1.9	2.3	3.4	1.7	0.4	3.2
Top Bark	0.7	1.1	0.6	0.2	1.9	0.7
Branches	14.8	26.2	37.8	17.5	33.2	26.4
Foliage	3.5	24.9	22.1	10.8	5.3	18.8
Top Sub-total	20.9	54.5	63.9	30.2	40.8	49.1

* Stump to 4-inches diameter-outside-bark.

Whole-tree harvesting would increase biomass removals by 26% while N removals would be increased by 120%, P by 177%, K by 43%, Ca by 69%, and Mg by 97%. Calcium and K show the least increases as also observed with water tupelo.

The black gum data (Table 7) shows a reduction in whole-tree harvesting nutrient removal effect as compared to water tupelo and water oak since it was sampled after leaf abscission.

Table 7. Dry weight and nutrient content of black gum expressed as percentage of aboveground totals.

Component	Wt.	N	P	K	Ca	Mg
Bole Wood	80.1	66.1	92.2	75.5	35.1	58.6
Bole Bark	7.8	15.5	2.3	9.6	50.7	17.5
Bole Subtotal*	87.9	81.6	94.5	85.1	85.8	76.1
Top Wood	2.6	3.8	1.4	2.6	0.8	2.2
Top Bark	0.7	2.0	0.4	1.2	3.5	2.2
Branches	8.8	12.6	3.7	11.1	9.9	19.5
Top Subtotal	12.1	18.4	5.5	14.9	14.2	23.9

* Stump to 4-inches diameter-outside-bark.

Whole-tree harvesting would increase biomass removals by 14% while N removals would be increased by 23%, P by 6%, K by 18%, Ca by 17%, and Mg by 31%. Since black gum was sampled after leaf abscission, only a general comparison can be made between this species and water tupelo and water oak.

Several factors must be considered when applying data such as that presented for water tupelo, water oak and black gum. It has been shown that just prior to leaf abscission all macronutrients and most micronutrients undergo some degree of translocation back from leaves into twigs (Likens and Bormann 1970). Therefore, post-abscission nutrient removals must be evaluated through sampling after leaf fall since subtracting foliage content from pre-abscission data will provide erroneous results.

Tables 5, 6, and 7 estimate nutrient removal from the site in biomass and do not show true system losses, particularly for nitrogen. Nitrogen losses can occur through leaching and denitrification as well as harvest removal. Rauscher (1980) determined that the greater the litter amount on the site after a harvest, the greater the loss of nitrogen from the system by leaching and denitrification. A whole-tree harvest will produce less litter than a bole harvest; therefore, the greater removal of N in biomass will be partially offset by the lower leaching and denitrification losses.

It is stressed that the estimates of removal provided are valid only for the species discussed growing in similar stand situations. Nutrient content is rather variable between species and even between trees of a single species growing in the same stand.

SUMMARY AND CONCLUSIONS

Several conclusions were drawn concerning nutrient levels and distribution in water tupelo, water oak, and black gum.

- Whole-tree harvesting can increase biomass removal over stem harvesting (stump to 4-inches diameter-outside-bark) by 20-26% and nutrient removal by 22-117% for a pre-abscission harvest.
- Elements most affected by whole-tree harvesting will be N and P; those least affected will be K and Ca.
- Elemental content by tree component was generally bole wood > branches > bole bark > foliage except for Ca where the order was stem bark > branches ≃ stem wood > foliage.

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LITERATURE CITED

Bormann, F. H., G. E. Likens, D. W. Fisher, and R. S. Pierce.
1968. Nutrient loss accelerated by clearcuttin of a forest ecosystem. Science 159:882-884.

Bowersox, T. W. and W. W. Ward.
1977. Seasonal variation in foliar nutrient concentrations of black cherry. Forest Sci. 23:429-432.

Boyle, J. R.
1975. Nutrients in relation to intensive cult of forest crops. Iowa State J. Res. 49: 297-303.

Boyle, J. R., J. J. Phillips, and A. R. Ek.
1973. "Whole-tree" harvesting: Nutrient budget evaluation. J. of Forestry 71:760-762.

Haines, S. G.
1978. Effects of whole-tree harvesting on for nutrient budgets. International Paper Co. Rep., Southlands Experimental Forest, Bainbridge, GA, 21 pp.

Likens, G. E. and F. H. Bormann.
1970. Chemical analysis of plant tissues from the Hubbard Brook ecosystems in New Hampshi Yale Univ., School of Forestry Bull. 79.

essina, M. G.
1980. Nutrient levels, distribution and variation in three bottomland hardwood species. Proceedings: Third Central Hardwood Forest Conference, University of Missouri, Columbia, Missouri (in press).

rrison, I. K. and N. W. Foster.
1979. Biomass and element removal by complete tree harvesting of medium rotation forest stands. P. 111-129. In: A. L. Leaf (ed.), Impact of Intensive Harvesting on Forest Nutrient Cycling. SUNY, Syracuse, N.Y.

itchett, W. L.
1979. Properties and Management of Forest Soils. Wiley, N.Y.

uscher, H. M.
1980. An analysis of nitrogen removal from southern Appalachian oak ecosystems by harvesting. Ph.D. Dissertation. V.P.I. and S.U., Blacksburg, VA. 145 pp.

lfe, G. L., M. A. Akhtar, and L. E. Arnold.
1978. Nutrient distribution and flux in a mature oak-hickory forest. Forest Sci. 24: 122-130.

ite, E. H.
1974. Whole-tree harvesting depletes soil nutrients. Can. J. For. Res, 4:530-535.

BIOMASS AND NUTRIENT ACCUMULATIONS OF AN UNEVEN-AGED SOUTHERN PINE STAND IN ARKANSAS[1]

Timothy T. Ku, Laurin Wheeler, Jack F. Young,
Robert J. Colvin, Michael F. Dziadzio
and John H. King[2]

Abstract.--Destructive sampling was used to determine the aboveground biomass and nutrient content of overstory components in a natural, uneven-aged loblolly (Pinus teada L.) and shortleaf (Pinus echinata Mill.) pine stand on a Sacul soil of the Upper Coastal Plain region in south Arkansas.

The soil was Sacul loam, a clayey, mixed, thermic, Aquic Hapludult, on a moderately well-drained upland pine site. The stand from which the sample trees were harvested had 532 stems/ha (10 cm dbh and over), 22.7 M^2/ha of basal area. The largest trees were 77 years old. The ratio of loblolly to shortleaf pine in the stand was nearly 2:1 in both number of trees and in basal area per hectare. Diameter distribution of the stand had a q-value of approximately 1.56.

The felled sample trees were separated into component parts in the field. Standard procedures were used to determine the biomass dry weight at 70°C. Subsamples from each tree component were ground for chemical analysis of N, P, K, Ca, and Mg.

The least squares method was used to determine the relationship between tree components and D^2H, where D was dbh and H was total height of the sample tree. Regression equations of the general form:

$$\ln(\text{Biomass of Tree Components}) = A + B \ln(D^2H)$$

were used with stand tables to estimate biomass of each tree component. The stand dry weights in stemwood, stembark, live branches, dead branches and needles were: 80, 8, 16, 2 and 5 dry metric tons per hectare (T/ha), or 72, 7, 15, 2 and 4 percent of the total biomass, respectively. Total biomass production was 111 T/ha.

Nutrient accumulation of N, P, K, Ca and Mg in the total biomass were: 191, 9, 36, 69, and 33 Kg/ha, respectively. 40% of N and P, and 60% of K, Ca, and Mg were accumulated in the stems.

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INTERACTION OF SITE, CULTURAL PRACTICES, AND TREE SPECIES ON DRY MATTER ACCUMULATION IN BIOMASS PLANTATIONS

P. E. Pope and J. D. Rhodes[1]

Abstract.--After two growing seasons black locust averaged 317 and 189 cm in height and 25 and 26 mm in diameter on the forest land (FL) and old field (OF) sites, respectively. Sycamore averaged 109 and 95 cm in height and 14 and 11 mm in diameter on the FL and OF sites, respectively after the same period of time. Initial spacing and fertilization had no effect on seedling survival but increased spacing significantly increased average seedling dry weight. Total aboveground biomass was significantly influenced by tree species, site, fertilization and initial spacing. The OF site showed the greatest growth response for fertilization.

INTRODUCTION

An uninterrupted supply of wood fiber is esential to accommodate a growing forest products idustry. Wood is also the largest biomass eergy resource in the United States and its iportance as an alternate of supplemental fuel i dramatized by recent fossil fuel shortages. Te Office of Technology Assessment (1980) iicates woody biomass, in addition to its taditional uses, will play a major role in fture energy production through gasification or cnversion to liquid fuels. In the short run mst of the energy resource needs from biomass i expected to come from residues in conventional hrvesting but an increase in the intensity of frest management, including the establishment o biomass/silage plantations, is essential to aieve the projected energy yield from wood wile maintaining the supply of material to forest iiustries.

Closely spaced, short rotation and intensive-l cultured fiber plantations can contribute lge quantities of biomass (McAlpine et al., 156; Kormanik et al., 1973; Kennedy, 1975 and Wtwer et al., 1978). Factors which influence fer yields include site (Broadfoot et al., 1/1; Wittwer et al., 1978), site preparation (rter and White, 1970), planting stock (Kennedy, 1/2; Steinbeck and McAlpine, 1973; Belanger and Saucier, 1975), spacing (Belanger and Pepper, 1978; Wittwer et al., 1978), cultural treatments, including weed control (McKnight, 1970) and fertilization (Blackmon and White, 1972), and harvesting interval (Balanger and Saucier, 1975; Kennedy, 1975; Perala, 1979) and season (Clark, 1975; Balanger, 1979). In addition, efforts have been made to determine the productive potential of root stocks (Balanger, 1979; Perala, 1979) and to access the impacts of short rotations and intensive harvesting on long term site productivity (Blackmon, 1979; DeBill and Radwan, 1979).

In many areas of the country, sites relegated for forestry use are stressful and are marginally productive. The objectives of this study are to compare the productivity of a stressful site to a typical forest land site and to determine the influence of tree species, fertilization and spacing density on dry matter yields.

MATERIALS AND METHODS

Species and Site Selection

Two tree species, black locust (Robinia pseudoacacia L.) and American sycamore (Platanus occidentalis L.) were selected for evaluation of dry matter production under the short rotation/silage plantation concept. Two planting sites were identified: (1) abandoned old field and (2) forest land (Table 1). A fragipan is present in both the old field and forest land soils at 38 and 110 cm, respectively.

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Table 1.--Site characteristics of the two locations assessed for woody biomass production.

	Old Field	Forest Land
Soil Type	Zanesville (Typic Fragidalfs, fine-silty, mixed mesic) Eroded Phase	Fincastle (Aeric, Ochraqualfs [Typic], fine-silty, mixed, mesic) Somewhat Poorly Drained
Slope (%)	5-7	1-3
Aspect	SW	-
Estimated Site Index[1]	55-60	85-90

[1] Site index at a base age of 50 years for Yellow poplar (Liriodendron tulipifera).

Spacing

Prior to experimental plot layout, the old field and forest land sites were plowed and disced in the fall of 1978 in preparation for seedling planting in May 1979. One-year-old bareroot nursery seedlings were planted in pure stands at densities equivalent to 5,000, 10,000 and 20,000 plants per ha, representing spacings of 2 x 1, 1 x 1 and 0.5 x 1 meters.

Fertilization and Weed Control

Following site preparation soil samples 0-30 and 30-60 cm in depth were collected from 25 locations identified at random on each site and analyzed for chemical properties. Similarly, soil samples were collected in September each year from one random location in each of the 36 subplots on each site and analyzed (Table 2). Available soil P was determined colorimetrically using ammonium molybdate reagent following extraction with Bray I solution, available K, Ca and Mg determinations followed extraction with IN ammonium acetate, and NH_4-N and NO_3-N values were determined following 2N KCl extraction and Kjeldahl distillation.

Fertilizer treatments, applied in May 1979 and 1980, consisted of no fertilization or a broadcast application of N, P and K at rates equivalent to 100, 50 and 50 kg/ha, respectively, of elemental material for sycamore and P and K each at 50 kg/ha of elemental material for black locust. In all cases nitrogen was added as ammonium nitrate, phosphorus as superphosphate and potassium as potash. Weed control was provided by mechanical cultivation during early June and by mowing in mid-July and late August or as needed.

Experimental Design

At each location, the two species and two fertilizer treatment combinations were randomized over three blocks forming 12 main plots. The three spacings were randomly assigned to subplots within each main plot. Each subplot was 12 x 12 meters. All trees in the center 32 m^2 of each subplot (net plots) were measured. This arrangement provides for a minimum of 27 measurement trees for the 2 x 1 m spacing, 45 trees for the 1 x 1 m spacing and 81 trees for the 0.5 x 1 m spacing. Inherent with spacing studies is the necessity of choosing between unequal subclass numbers when a unit area constitutes the measurement plot or risking heterogeneity of variance if surface area varies. The study was arranged in a randomized complete block design and analyses based on unequal sample size.

Data Acquisition and Analysis

Stem height, diameter at a 10 cm height, and survival were determined annually for all plot trees. Six sample stems were harvested annually from the interior border rows and height, diameter at 10 cm stump height, and green and oven dry weight of foliage and stem components determined. Biomass of the net plot t trees was estimated by a biomass to volume modele determined for the harvested trees. All data were analyzed by ANOVA and Duncan's new multiple range test.

RESULTS AND DISCUSSION

Black locust seedling survival, and first and second year height and diameter growth exceeded the survival and growth attained by sycamore for the two sites investigated. After two years seedling survival averaged 96% for locust and 84% for sycamore and was not affecte by site or cultural treatments. After the firs and second growing seasons black locust growing on the forest land (FL) site was significantly taller and larger in diameter than locust seedlings grown on the old field (OF) site (Table 3 However, after the second growing season, the growth advantage associated with fertilizing black locust was no longer evident for either t FL or OF site. After the first growing season, the height and diameter growth of sycamore was not influenced by site and fertilization; howev by the end of the second growing season, fertilization significantly increased the height and diameter of sycamore on the OF site. Differenc in inherent site productivity are also beginnin to emerge. Seedlings receiving no fertilizer a grown on the PFL site were significantly large than seedlings for the identical treatment on t OF site.

Site and initial spacing significantly influence the individual aboveground dry weigh of black locust seedlings (Table 4). After tw

Table 2.--Chemical analysis of the three biomass sites before fertilization and after one growing season. (Unless otherwise indicated, all values are reported as ppm.)

	Forest Land				Old Field			
	May 1979[1] (cm)		September 1979[2] (cm)		May 1979 (cm)		September 1979 (cm)	
	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60
pH	6.4	5.8	6.2	5.9	5.6	5.3	5.4	5.3
O.m(%)	1.2	0.4	1.3	0.6	1.5	0.4	1.3	0.6
NH_4-N	1.8	1.4	1.6	1.8	2.6	1.5	2.0	1.7
NO_3-N	2.0	3.0	1.9	2.6	0.8	1.6	1.2	1.6
P	20	3	32	51	2.5	2.5	12.5	3
K	125	100	133	109	40	46	78	52
Ca	1460	1933	1371	1900	500	546	471	540
Mg	340	590	361	560	100	257	93	265

[1] Chemical analysis before fertilization.

[2] Chemical analysis after one growing season.

Table 3.--Fertilization, species and land classification influence seedling height and diameter growth after 1 and 2 years.

	Black Locust				Sycamore			
	Fertilized		Not Fert.		Fertilized		Not Fert.	
Land Classification	Ht. (cm)	Diam. (mm)	Ht. (cm)	Diam. (mm)	Ht. (cm)	Diam. (mm)	Ht. (cm)	Diam. (mm)
Forest Land								
Year 1	162 x [1],*[2]	16.4x	117x	16.1x	83x	9.7x	69x	8.2x
Year 2	331a[1]	27.7a	304a	.1a	113a	13.8a	104a	13.8a
Old Field								
Year 1	73y*	7.1y	42y	6.3y	61x	9.2x	43x	8.5x
Year 2	169b	12.4b	169b	12.9b	109a*	12.2a*	80.2b	9.6b

[1] Column values for a given species and year not followed by the same letter are significantly different (α = .05). Note: x-y for year 1; a-b for year 2.

[2] Row values for a given growth variable, species, land classification and year having a * are significantly different (α = .05).

growing seasons, black locust seedlings averaged 1[illegible]7 g/seedling on the FL site and 248 g/seedling on the OF site. For the FL site, the average total aboveground dry weight increased from 992 g to 1734 g/seedlings as initial spacing increased from 0.5 x 1 to 2 x 1 m spacings. This trend was reversed for locust growing on the OF site. Seedlings grown at the 0.5 x 1 m spacing had significantly more dry weight than seedlings grown at the 2 x 1 m spacing.

On the average, after two years, American sycamore accumulated 50 g of dry matter per seedling. On the FL site, seedling dry weight increased as initial spacing increased with significant gains noted for the 2 x 1 m spacing. Dry matter accumulation on the OF site was also influenced significantly by spacing but no clear reason for the observed response can be offered.

As planting spacings become wider, seedlings tend to become more branchy, have relatively more foliage and develop larger diameters. These generalizations appear to explain the growth response observed for black locust and sycamore on the FL site. The larger locust seedlings associated with the closer spacings on the OF site may have resulted from a reduction of interrow weed competition. Weed control was achieved by lightly tilling down each row in early June of each year followed by a down the row mowing in early July and August. Consequently, as seedling spacing increased the amount of competing vegetation also increased. While this same analogy also applies to the FL site, the species components of the competing vegetation differed greatly. The old field site was characterized by woody shrubs, scrub hardwood species, fescue and broomsedge while the PFL site supported annual

Table 4.--Influence of land classification and spacing on the dry matter of black locust and sycamore seedlings after 2 growing seasons. Values are present as grams/seedling).

Land Classification	Black Locust Spacing (m)	Black Locust Dry Wt. (grams)	Sycamore Spacing (m)	Sycamore Dry Wt. (grams)
Forest Land	.5 x 1	992b[1]	.5 x 1	45a
	1 x 1	1167ab	1 x 1	44a
	2 x 1	1734a	2 x 1	62b
Old Field	.5 x 1	262c	.5 x 1	40a
	1 x 1	275c	1 x 1	61b
	2 x 1	207d	2 x 1	46a

[1] Column values not followed by the same letter are significantly different ($\alpha = .05$).

grasses, foxtail, pigweed and pokeberry.

Obviously, the two tree species differ in their ability to respond to the sites and cultural practices tested. Black locust is a nitrogen-fixing species, and therefore capable of continuously supplying this essential element, which is capable of vigorous growth over a range of site conditions. American sycamore is more site specific than locust and is apparently not as competitive for soil moisture and nutrients. Sycamore is capable of rapid growth rates under the correct site conditions but it appears that these conditions have not been met in this study.

The total aboveground dry matter attained after two growing seasons is influenced by tree species, spacing, site and fertilization (Table 5). In general, biomass production was greatest for black locust on the FL (13.3×10^3 kg/ha) followed by the OF site (2.8×10^3 kg/ha). Dry matter production for sycamore averaged 0.54×10^3 kg/ha and was not significantly influenced by site.

For both species dry matter production/ha increased as initial spacing decreased from 2 x 1 to 0.5 x 1 m. Yield (10^3 kg/ha) is a function of individual plant size and plantation density. The yield values reported are illustrative of the importance of stand density in determining dry matter production of short rotation cellulosic crops.

Fertilization of black locust seedlings growing on the FL or OF sites at the 0.5 x 1 m spacing significantly reduced the dry matter production when compared to the unfertilized control (Table 5). Fertilization caused rapid early stem growth and foliage development, particularly for those trees in the closest spacing. Weed competition was minimal because the densely planted trees had, in effect, eliminated them and any added fertilizer was readily available to the locust seedlings. A severe drought in June and July 1980 stressed all trees but caused the densely planted fertilized seedlings to stop growing. Fertilized trees planted at wider spacings were not as severely affected. Competi vegetation may have absorbed much of the added fertilizer making it unavailable to the locust seedlings. While this obviously reduced the rat of early season growth, the seedlings appeared t be not as susceptable to drought stress as the rapidly growing seedlings. Fertilization had little effect on dry matter production on the FL site but may be essential to attain acceptable fiber yields on old field sites.

Sycamore yields, after two growing seasons, followed a slightly different pattern. Fertilization increased the yields (10^3 kg/ha) in the 0.5 x 1 m spacing on both the FL and OF sites. Except for the 2 x 1 m spacing on the OF site, yields from fertilized seedling plots tended to

Table 5.--Influence of land classification, initial spacing and fertilization on the dry matter production of black locust and sycamore plantations after one and two growing seasons. (Values presented as 10^3kg (metric tons)/ha.).

Land Classification	Spacing (m)	Black Locust Fertilized Year 1	Black Locust Fertilized Year 2	Black Locust Not Fert. Year 1	Black Locust Not Fert. Year 2	Sycamore Fertilized Year 1	Sycamore Fertilized Year 2	Sycamore Not Fert. Year 1	Sycamore Not Fert. Year 2
Forest Land	.5 x 1	2.2	17.00^{b}[1]	1.62	22.70^{a}	.43	1.08^{a}	.36	$.67^{ab}$
	1 x 1	1.1	11.80^{c}	.81	11.50^{c}	.22	$.32^{b}$	.18	$.56^{ab}$
	2 x 1	.6	8.90^{d}	.41	8.40^{d}	.11	$.31^{b}$	.09	$.31^{b}$
Old Field	.5 x 1	.24	3.90^{b}	.14	5.46^{a}	.20	1.06^{a}	.14	$.53^{b}$
	1 x 1	.12	2.91^{bc}	.07	$.87^{c}$	.10	$.57^{b}$	.07	$.65^{b}$
	2 x 1	.06	1.19^{c}	.04	$.92^{c}$	.50	$.33^{bc}$	.04	$.12^{c}$

[1] Row or column values for a given site species, and year not followed by the same letter are significantly different ($\alpha = .05$).

wer than those receiving no fertilizer. Again,
e competing weed populations absorbed much of
e added fertilizer, in effect negating this
eatment, and became a more effective compet-
or for the remaining soil water and nutrients.

SUMMARY

Yield of short rotation biomass plantations
n be significantly effected through species and
te selection, variation in plantation density
tems/ha) and cultural practices including fer-
lization. High fiber yields may be obtained
th proper species-site selection, but selection
an off-site species (in the case of this study,
camore) may result in unacceptable yields no
tter what cultural practices are included.
rginally productive forest lands may be used to
tablish biomass/silage plantations only with
reful attention to species selection and inten-
ve cultural treatments. Evaluations should be
de of the economic soundness of such an
dertaking.

LITERATURE CITED

Belanger, R. P., and J. R. Saucier.
1975. Intensive culture of hardwoods in the south. Iowa State J. Res. Vol. 49, No. 3, Pt. 2. 339-344

Belanger, R. P. and W. D. Pepper.
1978. Seedling density influences the early growth of planted sycamore. Forest Sci., Vol. 24, 4:493-496.

Belanger, R. P.
1979. Stump management increases coppice yield of sycamore. South. J. Applied For. 3:101-103.

Blackmon, B. G., and E. H. White.
1972. Nitrogen fertilization increases cottonwood growth on old field sites. USDA For. Serv. Research Note SO-143, 5 p.

Blackmon, B.G.
1979. Estimates of nutrient drain by dormant-season harvests of coppice American sycamore. USDA For. Serv., Research Note SO-245, 5 p.

Carter, M. C., and E. H. White.
1970. The necessity for intensive cultural treatment in cottonwood plantations. Pp. 28-38 in Silviculture and Management of Southern Hardwoods. T. Hansbrough, Ed. Louisiana State University Press, Baton Rouge, La.

Clark, A. III.
1975. Seasonal variation in weight of young coppice sycamore. Wood Science, 4:261-266.

DeBell, D. S., and M. A. Radwan.
1979. Growth and nitrogen relations of coppiced black cottonwood and red alder in pure and mixed plantings. Bot. Gaz. 140(Suppl.):S97-S101.

Kennedy, H. E., Jr.
1972. Horizontal planting of green ash cuttings looks promising. USDA For. Service, Research Note SO-147, 3 p.

Kennedy, H. E., Jr.
1975. Influence of cutting cycle and spacing on coppice sycamore yield. USDA For. Serv., Research Note SO-193, 3 p.

Kormanik, P. P., G. L. Tyre and R. P. Balanger.
1973. A case history of two periodically cut short-rotation coppice plantations on southern Piedmont bottoms. Pp. 351-360 in IUFRO Biomass studies. University of Maine Press, Orono, Maine.

McAlpine, R. G., C. L. Brown, A. M. Herrick, and H. E. Ruark.
1966. "Silage" sycamore. Forest Farmer XXVI:6-7,16.

McKnight, J. S.
1970. Planting cottonwood cuttings for timber production in the South. USDA For. Serv. Research Paper SO-60.

OTA - Office of Technology Assessment, Energy from Biological Processes, Volume 1. (Wash., D.C.: Office of Technology Assessment, U.S. Congress, May 1980).

Perala, D. A.
1976. Regeneration and productivity of aspen grown on repeated short rotations. USDA For. Serv. Research Pap. NC-176, 7 p.

Steinbeck, K., and R. G. McAlpine.
1973. Furrow planting American sycamore cuttings. Tree Planters' Notes 24:22-24.

Wittwer, R. F., R. H. King, J. M. Clayton, and O. W. Hinton.
1978. Biomass yield of short rotation American sycamore as influenced by site, fertilizers, spacing and rotation age. South. J. Applied For. 2:15-19.

CONCENTRATION AND DISTRIBUTION OF SELECTED ELEMENTS IN ABOVEGROUND BIOMASS OF 8-YEAR-OLD SLASH PINE[1]

Eugene Shoulders[2]

Abstract.--Concentrations of nitrogen, phosphorus, potassium, and magnesium followed the general order foliage > small branches > bole bark $\geq$ large branches $\geq$ bole wood, with certain exceptions. Concentration of these nutrients in needles and branches decreased with distance from apical meristems and were usually less in lower than in upper crown tissue. Calcium concentration in needles and branches increased with distance from apical meristems and were lower in current foliage from the upper crown than in older foliage or branches. Stem bark contained a higher concentration of calcium than stem wood. Foliage comprised only 22 percent of the above-ground dry weight of the trees, but contained 35 to 56 percent of individual nutrients. Bole wood and bark accounted for 58 percent of the biomass and contained 31 to 41 percent of the nutrients.

INTRODUCTION

Researchers need a thorough understanding of the variation in the concentration of nutrients between plant parts if they are to devise procedures for accurately estimating nutrient contents of forest crops. Individual tree data from a site amelioration study on a level to slightly sloping flatwoods site in central Louisiana (Shoulders and McKee 1974) provide preliminary estimates of these variations in 8-year-old slash pine plantations. In this paper, I report concentrations of nitrogen, phosphorus, potassium, calcium, and magnesium in foliage, branches, and boles, and the effects of tissue age and crown position on them. I also report relative amounts of each nutrient in different classes of tissue. Finally, I consider implications of these results in sampling trees and stands for nutrient contents.

MATERIALS AND METHODS

Four sample trees were harvested from each of 12 slash pine plots. The trees were taken from the second and third rows from the exterior of the plot. One tree was selected at random on each side of the plots from among individuals whose boles were free of disease or deformity. Trees were cut in September after they had completed most of the current season's growth but before they had begun to shed their older needles. Sample trees ranged in diameter at breast height (dbh) from 7.6 to 14.2 cm and in total height from 6.07 to 9.05 m. Their dry weights ranged from 8.4 to 39.6 kg.

Aerial parts above a 7.5 cm stump were separated into bole, upper crown branches, and lower crown branches. Branches from the two crown positions were further subdivided into:

1. Needles of the current year.
2. Older needles.
3. Twigs and branches of the current year.
4. Older needle bearing branches.
5. Live branch sections devoid of needles.
6. Dead branches.

Dead branches and bare, live branch segments wer present only in the lower crown.

Needle bearing portions of the upper stems were included with upper crown branches. Remai ing portions of the boles were sectioned acropetally into 1.2-m-long bolts. Identities f all classes of material from each tree were preserved throughout harvest and subsequent analys

Bole material was subsampled by cutting a 3.5-cm-long disk from the base of each bolt. E class of crown material was also subsampled.

Materials remaining after subsampling were dried to constant weight in a lumber kiln at ab 70°C and weighed.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

[2] Principal Silviculturist, Southern Forest Experiment Station, USDA Forest Service, Pineville, Louisiana. Drs. W. H. McKee, Jr. and B. F. McLemore designed the sampling procedure and collected the plant materials. Dr. McKee supervised laboratory analysis of the samples.

Subsample materials were ovendried to con- tant weight at 70°C after bark of bole samples as separated from wood. Subsample dry weights ere added to those of the main sample. Weights f bark and wood in individual segments of the ole were computed from proportions in the sub- amples. All subsample materials were ground to ass a 1.5-mm screen and their nutrient contents easured. Nitrogen was determined by the Kjeldahl ethod (Jackson, 1958). Other analyses were made material dry-ashed for 2 hours at 450°C and ken up in 0.3N HNO_3. Phosphorus was determined the molybdovanadate procedure (Jackson, 1958), d potassium, calcium, and magnesium by atomic sorption.

Total amounts of individual nutrients in the ee segments were computed. Proportions of each ee's weights and nutrient contents in every ass of material were then determined.

Differences between treatments and tree seg- nts in concentrations of nutrients and in pro- rtion of the trees' total content were tested analyses of variance and Duncan's new multiple nge test with significance at the 0.05 level.

The site amelioration treatments (control, at disking, and bedding) affected tree size t did not influence significantly the proportions total weight in stem wood, stembark, branches, d needles (McKee and Shoulders 1974) or the ncentration of nutrients in various plant parts. erefore, results reported here are averages for sample trees.

RESULTS

oncentrations of Nutrients in Tree Segments

Concentrations of nitrogen in tissues ranged m 0.144 to 0.792 percent, of phosphorus from 18 to 0.091 percent, of potassium from 0.028 0.606 percent, of calcium from 0.084 to 0.399 cent, and of magnesium from 0.039 to 0.123 cent (table 1). Except that dead limbs and -needle bearing segments of live branches from lower crown contained similar percentages of nutrients, every plant part sampled differed nificantly from every other in concentration one or more elements.

Percentages of nitrogen, phosphorus, potassium, magnesium were always significantly higher needles than in the branch segments that bore m. In older tissues, calcium was also more ndant in needles than in branches. But current needles and branch segments contained similar centrations of calcium.

Levels of nitrogen, phosphorus, and potassium e higher and of calcium lower in current year dles and twigs from the upper crown than in ilar tissues from the lower crown. Crown ition did not affect magnesium levels in rent foliage, but current year twigs from the upper crown contained higher percentages of magnesium than their lower crown counterparts.

In older needles and needle-bearing branch segments, crown position affected only potassium, calcium, and magnesium levels. Potassium was significantly higher and calcium significantly lower in upper crown needles and branches than in like tissues from the lower crown. Magnesium was less abundant in older needles from the upper than in older needles from the lower crown.

In the upper crown, current year needles and twigs contained higher concentrations of nitrogen, phosphorus, potassium and magnesium and lower concentrations of calcium than older needles and branches. Except for phosphorus in foliage, these differences were significant. Similar trends developed in lower crown tissues but differences were usually smaller and fewer of them were significant.

Older needle bearing branches from the lower crown had higher concentrations, usually significantly so, of nitrogen, phosphorus, potassium, and magnesium than dead limbs and non-needle-bearing branch segments of live branches. Calcium levels, however, tended to be lower in needle- than in non-needle bearing live branch segments. As noted earlier, non-needle bearing live branch segments and dead limbs contained similar concentrations of all nutrients.

No clear trend emerged in nutrient levels in bole wood or bole bark relative to height in the stem. These results apply only to portions of the bole devoid of needles, as needle bearing portions of the main stem were included with upper crown branches. In the needle bearing portion of the bole, concentrations of nitrogen, phosphorus, potassium, and magnesium probably increased and of calcium decreased with height.

Nutrient levels were higher in bark than in wood. Except for phosphorus, these differences were significant. Bark also contained higher concentrations of nitrogen and potassium than non-needle bearing live branch segments and of magnesium than all branch tissue except current-year twigs from the upper crown.

Stem wood resembled dead limbs and non-needle-bearing segments of live branches in concentrations of nitrogen, phosphorus, potassium, and magnesium. Calcium levels, however, were significantly lower in wood than in any other tissue.

Table 1.--Nutrient concentration in segments of the tree biomass from 8-year-old slash pine

Segment and Age	Nutrient concentration[1/] N	P	K	Ca	Mg
	Mg/g				
			Foliage		
Upper crown					
Current	7.92 ± .73g[2/]	.91 ± .29f	6.06 ± 1.88h	1.59 ± .69b	1.15 ± .21e
Older	7.13 ± .81f	.88 ± .35ef	3.14 ± 1.29f	3.03 ± .80d	.93 ± .19d
Lower crown					
Current	7.21 ± .54f	.77 ± .25e	3.63 ± 1.07g	2.17 ± .68c	1.23 ± .16e
Older	7.02 ± .74f	.86 ± .40ef	2.04 ± .97de	3.99 ± 1.08e	1.19 ± .25e
			Branches		
Upper crown					
Current	2.93 ± .74e	.44 ± .16d	3.85 ± 1.43g	1.74 ± .64b	.82 ± .22c
Needle bearing, over 1-yr-old	2.07 ± .31c	.25 ± .12bc	1.73 ± .56cd	2.17 ± .61c	.69 ± .10b
Lower crown					
Current	2.30 ± .30d	.32 ± .12c	2.37 ± .98e	2.27 ± .73c	.69 ± .15b
Needle bearing, over 1-yr-old	1.97 ± .25c	.24 ± .13bc	1.20 ± .42b	3.00 ± .68d	.67 ± .15b
Non-needle bearing	1.46 ± .19a	.14 ± .08ab	.70 ± .59a	3.35 ± 1.06d	.43 ± .10a
Dead	1.61 ± .36ab	.10 ± .07a	.28 ± .34a	3.25 ± 1.33d	.39 ± .10a
			Bole		
Bark	1.74 ± .17b	.22 ± .07abc	1.39 ± .47bc	1.59 ± .48b	.90 ± .70cd
Wood	1.44 ± .22a	.18 ± .10ab	.66 ± .18a	.84 ± .31a	.42 ± .34a

[1/] Values in any column with the same letter are not significantly different at the 0.05 level.

[2/] Standard deviation for nutrient concentration in segment. Standard error of means may be derived by dividing Standard deviations by $\sqrt{48}$.

Amounts of Nutrients in Tree Segments

Foliage comprised only 22 percent of the aboveground biomass of these 8-year-old trees. But it contained 56 percent of the nitrogen, 54 percent of the phosphorus, 49 percent of the potassium, 35 percent of the calcium, and 39 percent of the magnesium in aerial parts (fig. 1). In contrast, wood and bark of the bole contained 58 percent of the trees' dry weights and only 31 to 42 percent of the aboveground nutrients. Twenty percent of the biomass was in limbs. They contained 14 percent of the nitrogen and phosphorus in the trees, 20 percent of the potassium, 30 percent of the calcium, and 19 percent of the magnesium.

Implications in Sampling

Coefficients of variation for nutrient concentrations in individual plant parts ($\frac{\text{standard deviation}}{\text{mean concentration}}$ x 100) ranged from 7 perce for nitrogen in current needles from the lower crown to 121 percent for potassium in dead bra Coefficients of variation for concentrations o individual nutrients in foliage and needle bea branch segments did not exceed 55 percent. Fo these portions of the crown, a sample of 31 tr should estimate concentrations of all nutrient within ± 10 percent two-thirds of the time. F a 1-in-20 chance of error in sampling, 121 tre would be required. Samples of these sizes sho estimate concentrations of nitrogen in current needles from the lower crown within ± 1.4 perc and concentrations of potassium in dead branch within ± 22 percent.

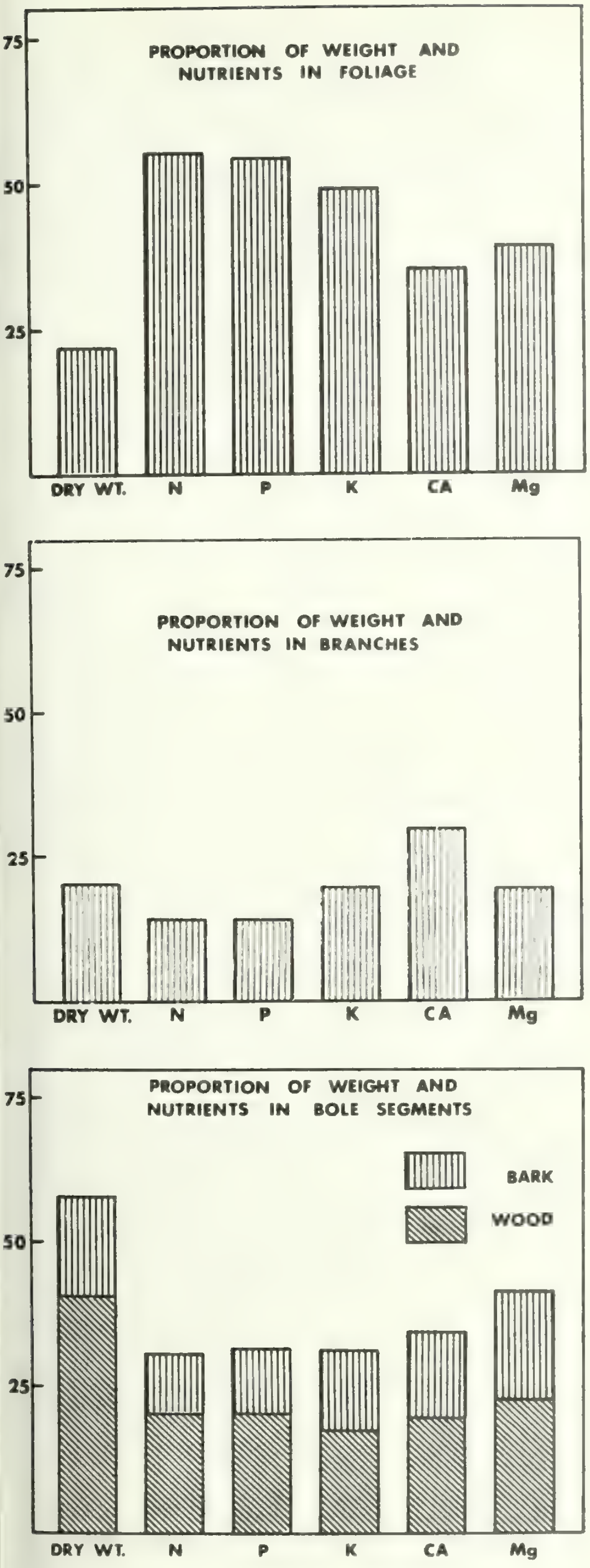

Figure 1--Distribution of weight and nutrients in aerial parts of 8-year-old slash pine trees.

DISCUSSION AND CONCLUSIONS

Obviously, data for 48 trees from one 8-year-old plantation are inadequate to characterize concentrations, amounts, or distribution of nutrients in aboveground tissues of slash pine trees. Concentrations of nutrients in tissues vary with soil fertility (Pritchett 1968, Ballard and Pritchett 1975) and soil moisture regime (White and Pritchett 1970, White et al. 1972). Work with other species (Wells and Metz 1963) and unpublished data from our laboratory show that concentrations in foliage vary seasonally. Site, age, and stand density affect proportions of nutrients in individual parts by altering the distribution of the total biomass among tissues (Metz and Wells, 1965, Rennie 1966, Switzer et al. 1968) and perhaps by affecting concentrations of nutrients in individual segments.

For the most part, the task of quantifying these relationships lies ahead. Data presented in this paper suggests that it will not be easy. Foliage, branches, bark, and wood differ greatly in nutrient concentrations. Within foliage and branches, concentrations vary with position in the crown and age of tissue. All these factors must be considered in devising a sampling scheme to estimate nutrient content of trees and stands.

LITERATURE CITED

Ballard, R., and W. L. Pritchett.
1975. Soil testing as a guide to phosphorus fertilization of young pine plantations in the coastal plain. Fla. Agric. Exp. Sta. Tech. Bull. 778, 22 p. Univ. Fla., Gainesville.
Jackson, M. L.
1958. Soil chemical analysis. Prentice-Hall, Inc., Englewood Cliffs, N.J., 498 p.
Metz, L. J., and C. G. Wells.
1965. Weight and nutrient content of the aboveground parts of some loblolly pines. U. S. Dep. Agric., For. Serv., Res. Pap. SE 17, 20 p. Southeast. For. Exp. Stn., Asheville, N.C.
McKee, W. H., Jr., and E. Shoulders.
1974. Slash pine biomass response to site preparation and soil properties. Soil Sci. Soc. Am. Proc. 38:144-148.
Pritchett, W. L.
1968. Progress in the development of techniques and standards for soil and foliar diagnosis of phosphorus deficiency in slash pine. IN Forest Fertilization--Theory and Practice, p. 81-87. Tenn. Valley Auth., Muscle Shoals, Ala.
Rennie, P. J.
1966. A forest--sampling procedure for nutrient-uptake studies. Commonw. For. Rev. 45:119-128.
Switzer, G. L., L. E. Nelson, and W. H. Smith.
1968. The mineral cycle in forest stands. IN Forest Fertilization--Theory and Practice, p. 1-9. Tenn. Valley Auth., Muscle Shoals, Ala.
Wells, C. G., and L. J. Metz.
1963. Variation in nutrient content of loblolly pine needles with season, age, soil, and position on the crown. Soil Sci. Soc. Am. Proc. 27:90-93.

White, E. H., and W. L. Pritchett.
1970. Water table control and fertilization for pine production in the flatwoods. Fla. Agric. Exp. Sta. Tech. Bull. 743, 41 p. Univ. Fla., Gainesville.

White, E. H., W. L. Pritchett, and W. K. Robertson.
1972. Slash pine root biomass and nutrient concentrations. IN Forest Biomass Studies, p. 163-176. College of Life Sciences and Agriculture, University of Maine at Orono.

THE PATTERN OF NATURAL REGENERATION AND HEIGHT STRATIFICATION WITHIN A NATURALLY-CREATED OPENING IN AN ALL-AGED PIEDMONT DECIDUOUS FOREST[1][3]

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Abstract.--Detailed species inventories over a 4-year period within a natural opening created by a combination of storm damage, pine beetle damage, and windthrow in an old-growth Piedmont deciduous forest revealed distinct patterns of species density shifts, species regeneration and survival, and height stratification. Between 4 and 7 years after canopy opening relative densities of loblolly pine and yellow-poplar decreased markedly. Relative densities increased moderately among black cherry, sweetgum, and flowering dogwood and increased markedly among the oaks and hickories. By the end of the seventh growing season a distinct pattern of height stratification was evident. Above 160 cm loblolly pine, sweetgum, and flowering dogwood were dominant in a 2:1:1 ratio. Between 51-160 cm loblolly pine, black cherry, sweetgum and flowering dogwood were dominant in a 4:2:1:1 ratio. Between 11-50 cm black cherry, sweetgum, and various oaks were dominant in a 3:1:1 ratio. The lowest stratum, 10 cm and below, was dominated by black cherry, various oaks, and various hickories (2:1:1 ratio).

INTRODUCTION

The forests of the southeastern Piedmont, ike the deciduous forests of eastern North merica in general, are four-tiered communities omprised of herbaceous groundcover, shrubs, and ubcanopy and canopy arborescent strata. Despite his widespread and readily apparent vertical tructure, there has been little emphasis on etermining how early in the developmental equence of temperate deciduous forests this stratification occurs and its possible influences on community regeneration dynamics (e.g., differential germination, survival and mortality, and eventual establishment). As Smith (1973) noted, there has been almost no critical or systematic examination of processes of stratal development within forest communities.

Contemporary viewpoints on natural regeneration in temperate deciduous forests have derived from the early work of Jones (1945), Watt (1947), and Bray (1956). Natural regeneration consequently is viewed by many workers as the cyclical species replacements occurring within openings or "gaps" occasionally created in the forest by natural events, sometimes catastrophic and spectacular, sometimes relatively minor and more subtle (Forcier 1975, Fox 1977, Brewer and Merritt 1978, Barden 1979, Ehrenfeld 1980). Windthrow, glaze storms, and occasional insect infestations are major causes of gap formation on the southeastern Piedmont. Less spectacular but probably equally important is the death and fall of trees from the rigors of age such as fungal and/or viral pathogens. The main focus in most studies of gaps has been on the sequence of species shifts or on the ultimate stand composition that results within such openings over long timespans.

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For example, several studies were conducted following the loss of the American chesnut (*Castanea dentata* (Marsh.) Borkh.) from the forests of eastern North America. These studies emphasized species replacements and shifts in community composition among various forests of the region (Keever 1953, Nelson 1955, Mackey and Sivec 1973, Stephenson 1974). Other studies of gaps and openings have assessed and evaluated various silvicultural practices, particularly clearcutting or seed tree cutting (Wendel 1975, McGee and Hooper 1975, Johnson and Krinard 1976). Other studies have been conducted to quantify the early colonization and short- and intermediate-term survival of woody species within canopy gaps (Skeen 1976) or the response of understory species following natural creation of different-sized gaps (Ehrenfeld 1980). A central premise in all these studies, either expressed or implied, has been that the resulting forest community is a mosaic or patchwork of abutting or overlapping gaps created at different times. In these gaps most trees would have initiated in a few years following gap creation. On a larger-than-gap-size scale, the resulting forest generally appears as a mixture of trees of many species having different ages and (usually) different sizes--the classical "all-aged" forest. Oliver (1980) recently has suggested that mixed-species forests in the eastern and northwestern United States, particularly after management manipulations creating large openings, may develop essentially even-age patterns internally. These forests may exhibit a deceptive vertical stratification that could appear all-aged to the casual observer. Consequently, a knowledge of past management practices, natural species replacement/regeneration sequences and patterns of vertical sorting between species during the stand's developmental stages may be imperative in prescribing appropriate management practices.

Opening size has been repeatedly stressed as an important determinant affecting regeneration, survival, establishment, height growth pattern, and eventual species composition in forest gaps (Jones 1945, Jackson 1959, Ehrenfeld 1980). But no detailed study has appeared that considers the vertical stratification within gaps in the early years after canopy opening. The sheltering effect of such internal gap development probably ameliorates gap microclimate and may possibly exert as great a controlling influence on internal gap species dynamics as does gap size, proximity to seed sources, surrounding canopy height, etc.

Understanding gap dynamics and patterns of internal forest development requires documenting and quantifying the pattern and sequence of changes in species composition, survival/mortality, and establishment during the early stages of natural regeneration. Equally important--particularly in view of Oliver's recent (1980) contentions--is consideration of questions regarding early vertical stratification in canopy gaps: Is vertical pattern apparent in the early years of gap phase replacement; if so, how early does it occur in the developmental/regeneration sequence? If pattern occurs--if there are two or more well-defined layers--are there compositional differences between the layers; if so, can the component species' silvicultural traits account for the pattern(s) observed? From the existing species mix and any early vertical pattern observed, does it appear likely that the vertical structure will increase or diminish in complexity are species seemingly being lost or replaced as dominants? The major aim of the present study--a part of a larger, long-range effort--was to gather and evaluate data which might suggest answers to these and related questions.

SITE CHARACTERISTICS AND STUDY PLAN

Obviously attempts to formulate answers to these and similar questions could be made from data derived from studies following either of two basic approaches--either the detailed study of multiple gaps of different ages at a single point in time, or the intensive study of a sin gap over many years. This study has followed the latter approach.

Site Characteristics

The study gap was in Fernbank Forest, a metropolitan Atlanta (33°46'N, 85°19'W) woodla of 25 ha. The forest has been described as a relatively mature hardwood forest (Skeen 1974) and, more recently, as a remnant (Wharton 1978 or relict (Dew 1980) of what original Piedmont forests on favorable sites may have been like. The forest would be termed a bluff-ravine fores with northern affinites according to the class fication of Wharton (1978) and a north-facing bluff forest after the Piedmont forest classification of Oosting (1942). It lies within th Atlantic slope section of the Oak-Pine Forest region described by Braun (1950) and most clo approximates SAF cover-type 59 (yellow-poplar white oak--northern red oak) (Society of Amer Foresters 1964). Canopy dominants, in order decreasing importance, include yellow-poplar (*Liriodendron tulipifera* L.), white oak (*Quer* alba L.), hickory (Carya glabra (Mill.)/C. tomentosa (Nutt.)/C. cordiformis (Wang.) K. Koch), northern red oak (Quercus rubra L.) and American beech (Fagus grandifolia Ehrh.) (Skeen 1974, Dew 1980). Mature pines (Pinus taeda L./P. echinata Mill.) have decreased in canopy importance since a severe southern pine beetle epidemic over the area in the early 1970's but are still highly visible and important canopy members. Tree density (>10.2 cm d.b.h.) within the forest is 447 trees/ha, basal area coverage is almost 38 m^2/ha, and above-ground biomass has been estimated as approximately 356 mt/ha (Skeen 1974).

Windthrow, glaze storm damage, and pine beetle damage have been severe in certain parts of the forest and have caused many canopy openings--some single-tree gaps and others multiple-tree gaps. Natural regeneration of both pine and hardwoods is now occurring in these openings. The site studied was one of the larger of these gaps (two or more canopy hardwoods have been lost 9-19 years ago and a single pine lost during the early 1970's beetle infestation). The rectangular clearing lay approximately 30 m inside the eastern boundary of the woodland and extended approximately 25 m east-west and about 15 m north-south. A predominantly deciduous canopy (25-30 m in height) bordered the clearing. Site elevation was approximately 340 m above mean sea level and the slope was approximately 5 percent facing southwest.

Methods

In early 1974 the 375 m^2 opening (25 m by 15 m) was subdivided into a permanently-marked grid network of 125 3 m by 1 m plots. The easternmost two-thirds of the opening (83 3 m by 1 m quadrats) was well along in the early stages of hardwood succession and was dominated by saplings grading, at that time, to about 5 m in height. The history of the origin and later regeneration of this older portion of the area ould not be documented with certainty so initial ttentions were focused on the younger, then pine-dominated, portion of the opening (42 3 m y 1 m quadrats). Spring/summer 1971 was the irst growing season (year 1) for the younger ortion of the opening.

Between mid-March and late May 1974 (early n growing season 4) a complete census was made f woody individuals present in the 42 3 m^2 uadrats comprising the most recently colonized rea. Each woody individual present, regardless f size, was assigned an identifying number and as individually marked with an aluminum tag. eedling and sapling categories were not differntiated by height classes in the initial census xcept to note new seedlings of the current year. The area was maintained free of outside disturbance, and the census was repeated in early March 1976 and late June 1977. Individuals that died between censuses were noted and new individuals which had appeared during the time interval were numbered and marked. Height measurements were also recorded during the 1977 census. The annual pattern of groundlevel global radiation in the opening was documented during the early colonization/establishment phase (mid-1974 to mid-1975) (March and Skeen 1976) and the near-ground (0-75 cm aboveground) thermal regimen--especially that following intense summer thunderstorms--was documented during the summer of 1974 (Skeen and March 1977). From the data obtained it has been possible to document the regeneration dynamics (early colonization, survival/mortality, establishment, etc.) that have occurred at 3 intervals during the first 7 years of colonization and reestablishment within the gap. The pattern of height growth occurring within the area by the end of the 7 years was recorded as well.

RESULTS

The inventories conducted early in the fourth (1974) and sixth (1976) growing seasons and midway through the seventh (1977) growing season revealed 18, 19, and 21 species-groups respectively (Oak and hickory designations consisted of multiple species, mostly indeterminable during early growth.). Throughout the three censuses, seven species-groups accounted for about 90 percent of the total number of individuals (93 percent, 91 percent, and 88 percent in 1974, 1976, and 1977) and were never represented by fewer than 9 individuals (absolute density of 714 stems/ha). These species-groups were loblolly pine (Pinus taeda L.), black cherry (Prunus serotina Ehrh.), tulip or yellow-poplar (Liriodendron tulipifera L.), sweetgum (Liquidambar styraciflua L.), flowering dogwood (Cornus florida L.), the hickories (Carya spp.), and the oaks (Quercus spp.). Other less important but frequently occurring species included red mulberry (Morus rubra L.), black gum (Nyssa sylvatica Marsh.), southern magnolia (exotic encroachment from residential plantings in the area) (Magnolia grandiflora L.), redbud (Cercis canadensis L.), and hawthorn (Crataegus sp.).

Density Relationships

The absolute density of individuals was approximately 43900 stems/ha in the 1974 census, 34800 stems/ha in the 1976 census, and 33400 stems/ha in the 1977 census. Figure 1 depicts the relative density or percentage composition attributable to each of the seven major species-groups at each census period. By the seventh growing season loblolly pine and yellow-poplar decreased markedly in relative density (38 percent

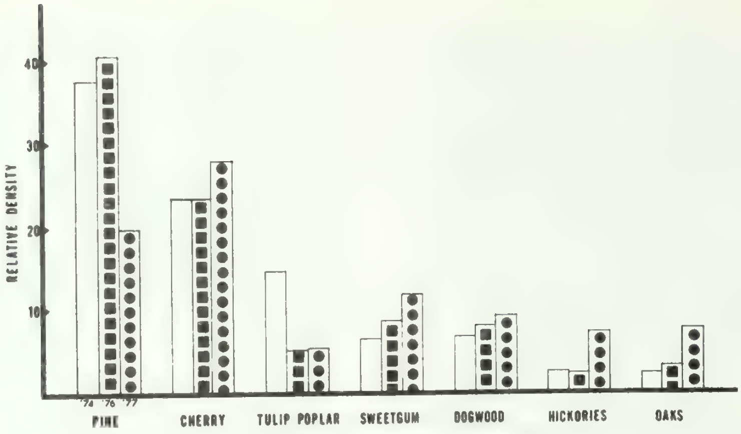

Figure 1.--Relative densities (percentage composition) of the seven most prominent species-groups early in year 4 (1974), early in year 6 (1976), and midway through year 7 (1977) after canopy opening.

to 20 percent, and 15 percent to 5 percent, respectively). Conversely, black cherry, sweetgum, and flowering dogwood increased moderately in relative densities over the timespan (24 percent to 28 percent, 7 percent to 12 percent, and 7 percent to 9 percent, respectively). The oaks and hickories, while making similar percentage gains, increased markedly in relative community composition (2 percent to 8 percent, and 2 percent to 7 percent, respectively), exhibiting a nearly four-fold increase in each instance.

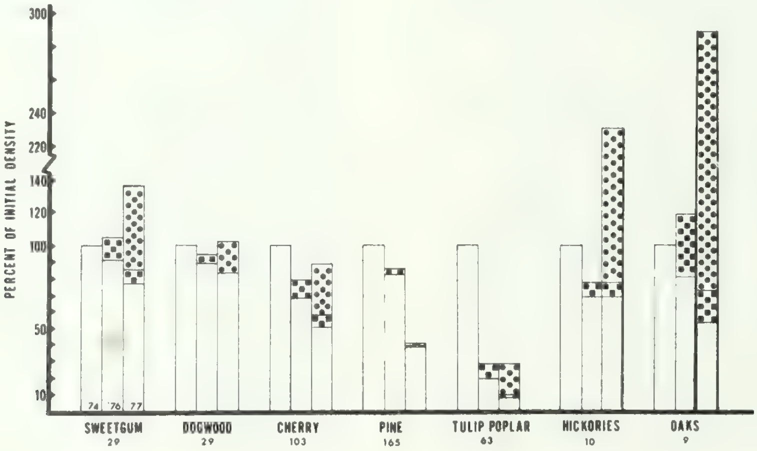

Figure 2.--Changes in densities within the seven most prominent species-groups over 3 years (1974-1977). All comparisons are made against respective species-group census values of the first census year (1974, year 4). Open bars represent the fates of original census individuals in subsequent years; square-stippled bars represent the fates of colonizers from the 1974-76 interval censused in 1976; and dot-stippled bars represent the colonizers from the 1976-77 interval censused in 1977. Values appearing below each species-group name represent the number of individuals within each group enumerated in the original (1974) census.

Reasons for these species shifts are parent in Figure 2. It shows the survivorship er time of the original (year 4) population of ch species plus new colonizers occurring within ch subsequent census interval and their survival pressed as a fraction of each species' original pulation density. Employing the original nsus count for each species as a basis of mparison and expressing all subsequent regen- ation, survival, and establishment relative to is base value clarified whether a species pop- ation was increasing or declining. Causal ctors such as high (or low) survival of the itial population or possibly subsequent lonization and survival as determinants of e shifts in relative densities also became parent. For example, the decrease in loblolly ne relative density is due to a survival of e original population of less than 40 percent year 7 coupled with both very low regeneration d very low survival of new colonizers in the me interval between years 4 and 7 (Figure 2). milarly, less than 8 percent of the original ear 4) yellow-poplar population survived until ar 7; new colonization and its survival over e interval was sufficient, however, to stabilize e yellow-poplar population at slightly less than percent of its initial (year 4) level. though black cherry, sweetgum, and flowering gwood are increasing in terms of relative mmunity proportion, only sweetgum and dogwood e increasing in terms of absolute numbers of dividuals relative to the original (year 4) nsus (Figure 2). The marked increase in the kories and oaks is due to moderately high rvival of the original populations (69 percent d 55 percent respectively) coupled with very gh colonization for both species between years 6 and 7.

Height Stratification

Figure 3 shows the pattern of aboveground stratification of woody species at the third census date (midway through the seventh growing season) after canopy opening (1977). Each species-group symbol shown represents an approximage density of 300 stems/ha. This profile diagram coupled with frequency histograms by height of each species-group suggested the occurrence of at least four strata. For this study these were set at 0-10 cm aboveground, 11-50 cm aboveground, 51-160 cm aboveground, and individuals greater than 160 cm aboveground.

Figure 4 reflects stratification recognizable within each species-group (narrow, patterned bars) as well as the vertical sorting by species-group within the community as a whole (wide, solid bars). Pines and dogwoods, for example, are most often encountered in the 51-160 cm stratum (narrow, patterned bars) while black cherry, yellow-poplar, sweetgum, and the oaks are most commonly encountered in the 11-50 cm stratum. The hickories are most often found in the lowest (0-10 cm) layer. If each height or stratum is considered individually (wide, solid bars), pines dominated the level above 160 cm with sweetgum and flowering dogwood also prominent (2:1:1 ratio). Between 51-160 cm in height, loblolly pine, black cherry, sweetgum, and dogwood occurred in a 4:2:1:1 ratio. Between 11-50 cm black cherry, sweetgum, and various oaks occurred in a 3:1:1 ratio with all other species-groups also represented in smaller proportions. The lowest stratum, 10 cm and below, was dominated

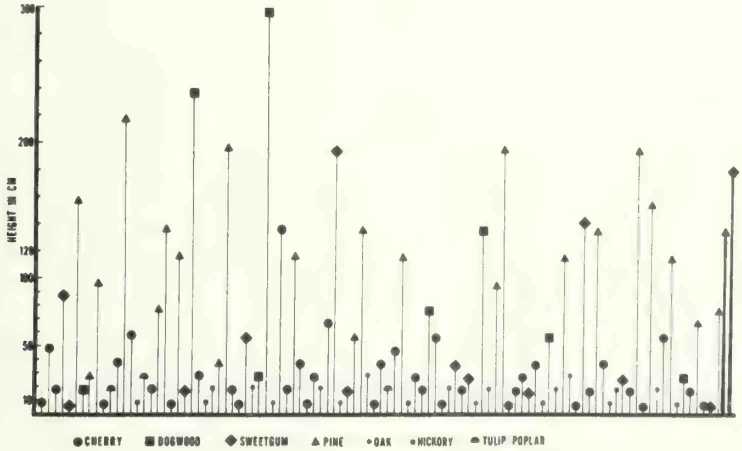

Figure 3.--Profile diagram of height stratification pattern in 126 m^2 clearing 7 years after canopy opening. Each symbol represents approximately 300 stems/ha (total stand density: 33400 stems/ha).

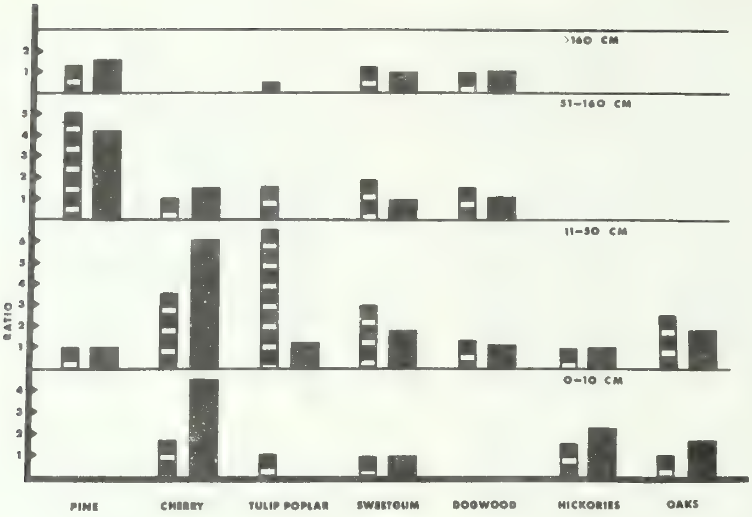

Figure 4.--Patterns of height distribution within each respective species-group (narrow, patterned bars) and species distributions within each stratum (wide, solid bars). (Narrow, patterned bars should be compared vertically within a single species-group; wide, solid bars should be compared horizontally within a single stratum.)

by black cherry, various oaks, various hickories, and sweetgum in a 5:2:2:1 ration. Thus pine and dogwood were essentially absent from the lowest (0-10 cm) stratum, all species-groups were well represented in the 11-50 cm stratum, oaks and hickories were essentially absent from the uppermost two strata (>51 cm), and black cherry was not encountered in the uppermost stratum (>160 cm).

DISCUSSION

Density Relationships

The density levels encountered in the year 4, year 6, and year 7 censuses (4.4 stems/m^2, 3.5 stems/m^2, and 3.3 stems/m^2, respectively) are within reasonable expectations (Skeen 1976) given the energy regimen within the clearing in the early years of colonization (March and Skeen 1976). Although most previously reported woody stem densities in natural forest regeneration studies have ranged between 1 and 2 stems/m^2 (Skeen 1976), such values generally have been obtained under well-developed forest canopies, not in canopy gaps. The present data suggest that decreasing stem densities occur with increasing vertical stratification and canopy closure (and with the consequent reduction of light intensities near ground level).

The shifts in relative densities observed largely parallel classical interpretations of the component species' tolerance to shade with the most intolerant species (loblolly pine and tu poplar, according to classical tolerances regimes decreasing markedly in community importance. The more shade-tolerant oaks and hickories exhibited pronounced increase in community importance. Dogwood, the most shade-tolerant of the component species, did not appear to be undergoing a pronounced shift toward increasing relative density and community importance. Such a response might be expected if shade tolerance alone were the ma determinant of early species success. There are several likely reasons for this paradox. There was no significant dogwood component in the lowe (0-10 cm) stratum (Figure 4). This suggests lit or no continuing seedling production or seedling survival by dogwood; this contention is substantiated by Figure 2 which indicates very low seed regeneration in both 1976 and 1977. Further, no of the seedlings produced in 1976 survived until 1977. This suggests that most of the dogwoods i the community are of vegetative origin. This suggestion is supported both by recent field obs -vation at the study site and by dogwood's well-k wn tendency to reproduce vegetatively (Fowells 1965 It is likely that many of the dogwoods recorded the upper three strata originated from sprouts a that at least the uppermost individuals were res n-ding initially to release. Further, if most or many of the original stems were in fact of sprou origin, the relative density of dogwood likely w overestimated since each stem was considered an individual plant and was enumerated and weighte equally.

The pattern of tulip poplar, generally considered a pioneer hardwood in the Southeast--but recently suggested as a component of climax or old-growth communities as well (Buckner and McCracken 1978; Skeen, Carter and Ragsdale 1980)--is also perplexing. Although the low survival encountered may be partially an artifact of difference in sampling season (early growing season in 1974, 1976; mid-season in 1977) as noted previously (Skeen 1976), our present understanding of tulip poplar's behavior is inadequate to explain (1) the continuing pronounced decline in survival of the original (1974) colonizers during later census intervals, (2) the determinants controlling sufficient regeneration to maintain the population at a relatively stable level (ca. 28 percent of initial density, 5 percent community relative density), and (3) how and when tulip poplar assumes sufficient prominence in the successional sequence to eventually become the most highly important species in the community (Skeen et al. 1980).

Although the oaks and hickories, relatively shade-tolerant community members, exhibited the most striking density shifts (Figures 1, 2), their absolute population densities were initially the lowest of the major species-groups. Consequently, on a comparative basis, a relatively modest increase in absolute density would lead to a many-fold increase on a relative basis. This was the case in the present study.

Vertical Pattern

Well-defined and highly structured vertical pattern occurs as early as year 7 after canopy opening. The questions remaining then become: (1) does measurable well-defined stratification possibly occur even earlier in the community's redevelopment sequence; (2) how many layers can be demonstrated; (3) are compositional differences evident between layers, and, (4) are ongoing species shifts apparent at the different levels? Without earlier height measurements it is impossible to tell whether well-defined vertical stratification does occur earlier than the seventh growing season. At least 4 strata can be easily demonstrated by year 7 (Figures 3, 4). Argument could be made for further subdividing the 51-160 cm stratum into two components--51-100 cm and 101-160 cm. The four well-defined strata emphasized seem adequate, however, for documenting vertical structure at this point of community development. Definite compositional differences occur between the respective strata (Figure 4)--each lower level is not merely a later-initiating layer with similar species composition to the next higher (and presumably earlier-initiating) stratum. The uppermost layer was dominated by loblolly pine, sweetgum, and dogwood (2:1:1 ratio). Observational evidence suggests that the pines are of seedling origin and that the dogwoods are mainly of vegetative origin and (at least the older and taller individuals) were released from suppression at the time of gap formation. The situation with regard to sweetgum is unclear. (Sweetgum's silvicultural traits encompass both possible seed and sprout origins, and both initiation at gap formation and from advance regeneration released from suppression.) The next lower level (51-160 cm) was dominated by the same three species--likely of similar origins--plus black cherry, probably of seedling origin. The next lower level (11-50 cm) was the most diverse and contained individuals of all seven species-groups. The relatively shade-tolerant oaks and hickories appeared in this level for the first time, a circumstance suggesting delayed initiation and/or slow growth. The lowest level (0-10 cm) lacked pine and dogwood and had no noteworthy tulip poplar indicating that these three species were no longer reproducing in the opening. Evidently, species shifts are occurring between the different levels with oaks and hickories yet to reach the uppermost strata and pines, dogwoods, and tulip poplars gradually disappearing from the lowermost. Such shifts closely parallel these species' classically-interpreted tolerance requirements with intolerant species gradually being replaced by more tolerant species.

Community Development Regime

In recent years several attempts have been made to reduce the continuous and highly integrated processes that occur during secondary succession or community development to generalized patterns that might allow inferences to be made about community origins, likely directional changes during development, and various properties (e.g., composition, stability) of the eventual end-state community (Goff 1968, Marks 1974, Forcier 1975, Connell and Slayter 1977, Fox 1977, Oliver and Stephens 1977). While these attempts have fostered critical thinking and stimulated important questioning about causes, directionality, and processes associated with community development, they have sometimes proven difficult to reconcile with observations made and data obtained in the field, especially if only a short time in the overall successional sequence is involved.

For example, Goff in 1968 introduced the ideas, later amplified by Auclair and Cottam (1971), of general compositional change versus gradient (successional) compositional change. General compositional change has been interpreted as species replacement principally dependent on differences in growth rate, mortality, etc., between species and generally irrespective of the particular species' environmental responses. Gradient compositional change has been understood as compositional shifts in response to specific ecological gradients. Great difficulty exists, however, in attempting to interpret the present data while divorcing such factors as height patterns, differential survivorship, etc., from the possibly controlling influences of environmental (light, temperature, moisture, etc.) gradients.

More closely allied to the patterns, processes, and problems of gap re-colonization addressed here are the response patterns suggested by Marks (1974) for forest ecosystems that have been subjected to distrubances of some sort. These patterns have subsequently come to be known as the "reorganization" response pattern in which vegetation established prior to the disturbance is structurally reorganized (e.g., canopy encroachment/crown compensation, epicormic branch formation, suckering, release of advance reproduction), and the "new establishment" response pattern which mainly concerns vegetation newly established (e.g., by direct seeding into gap or germination of dormant seeds already in place) after the disturbance. Ehrenfeld (1980) recently tested these ideas experimentally in a gypsy moth-defoliated forest in New Jersey in an attempt to determine whether gap size was critical in eliciting one response pattern as opposed to the other. She suggested that tolerance is a highly important determinant of community compositional shifts regardless of which pattern is encountered. Species more tolerant than those of the interrupted canopy are likely to emerge as dominant in the "reorganization" pattern and species less tolerant than those of the disrupted canopy are likely to emerge as dominant (at least for a time) if the "new establishment" pattern is followed. It is difficult at this early stage of community development to reconcile the present data and patterns as strictly supportive of one or the other of these two disturbance response patterns. However, both the shift in relative density documented and the pattern of height stratification (and apparent species replacements) noted parallel the classically-interpreted tolerance regime of intolerant species being replaced by more tolerant species. This pattern is suggestive, at least at this time, of the "new establishment" response pattern.

Both implicit in and complementary to the preceding ideas regarding general vs. gradient compositional change and "new establishment" vs. "reorganization" response patterns are the ideas set forth by Forcier (1975). He emphasized the importance of differences in reproductive strategies between co-occuring species in determining both intermediate and ultimate compositional patterns during successional/developmental sequences. Seed mobility, whether an initial or secondary colonizer, growth rate, and the potentiality to reproduce vegetatively were characteristics utilized to differentiate tolerant, slow-growing, stable species from opportunistic rapidly-growing species. A different experimental design with entirely different aims and objectives would be necessary to definitively categorize the species of the present canopy gap according to reproductive strategy patterns or gradients. Subjective observations coupled with a knowledge of the individual species' silvicultural traits suggest however that the prominent co-occuring species-groups express a diversity of reproductive strategies, both opportunistic and tolerant. Such a diversity of reproductive strategies doubtless greatly influences both the patterns of species co-occurrence and the eventual species replacements noted.

Connell and Slayter (1977) proposed three alternative models of compositional change occurring during succession or community development. The first model, paralleling the "relay floristics" idea of Egler (1954) has been termed the "facilitation" model and suggests that entry, establishment, and success of later species is dependent upon early species modifying the site in some fashion. This model was suggested as applying primarily, among plant communities, to certain cases of primary succession. The secondary successional models, paralleling the "initial floristic composition" idea of Egler (1954) have been termed the "tolerance" model and the "inhibition" model. The "tolerance" model suggests that species sequence occurs as a result of species having developed different strategies for exploitin community resources. Later-occuring species can supposedly tolerate lower levels of resources than earlier species and can consequently grow to maturity in the presence of their predecessors. The "inhibition" model holds that all species resist invasions of competitors and that the initial colonizers will occupy the available growing space. This spatial filling effectively excludes later colonizers until the death or injury of initial colonizers releases space and community resources for utilization by successors. This latter model, the inhibition model, was supported by Connell and Slayter's reasonings as the pattern most likely to be encountered during secondary succession in terrestrial ecosystems. In the absence of detailed measurements on site modifications by colonizing species and interspecies influences--lacking in virtually all regeneration investigations to date--it is conjectural to attempt to ascribe the present species-group behaviors as confirming one or another of the Connell-Slayter models. Argument could be made that all three models are likely operative--though not necessarily contemporaneously--in the early development sequence at the present site.

Also based on the ideas of Egler (1954) are the concepts of autogenic vs. allogenic successio elaborated by Oliver and Stephens (1977). Autogenic succession, analogous to the "relay floristics" idea mentioned previously (Egler 1954), is essentially a tolerance regime with increasingly more tolerant trees being recruited to the understory and a few old survivors eventually establishing in the overstory. Allogenic succession (Egler's "initial floristic composition") is essentially a disturbance/competition regime with available growing space and resources as the determinants of eventual canopy success. Oliver and Stephens (1977) suggested that in old-growth forest ecosystems the allogenic pattern of succession is likely of principal importance. The corollaries to this pattern are: (1) most trees in old-growth forests will initiate soon after major disturbances of some sort; (2) these disturbance-affected forests are consequently comprised of a mosaic of small stands, each of which begins following major disturbance; and, (3) the dominant canopy is comprised of a broad range of ages, the older members likely released from previous suppression and the younger dominants never having been suppressed. Allogenic succession, as elaborated here, results in a gap-phase pattern of spatial distribution (as opposed to a regular pattern of spatial organization associated with autogenic succession). Although the data of the present study did not consider age and spatial distributions for the forest as a whole--and therefore cannot definitively substantiate the existence of an allogenic successional pattern at the present site--observations and additional sampling conducted throughout the forest in the course of other studies are highly supportive of the allogenic pattern.

Fox (1977), in a study of the rates and mechanisms affecting species replacements in forest communities leading to cyclical species alternations, suggested that eventual species replacement is largely influenced by seedling microhabitat. The seedling microhabitat is in turn largely controlled by 1-few dominant trees at a given point and time. This local density and compositional regulation--brought about by highly localized biotic and abiotic habitat modification--controls the cyclical dynamics and suggests a coupling of the "facilitation" and "inhibition" models (sensu Connell and Slayter 1977) discussed previously. The pattern of species shifts that seems to be initiating at the present study site (decline in loblolly pine/yellow-poplar prominence, increase in oak-hickory prominence) could be interpreted as the possible first stage(s) in the formation of a pine/yellow-poplar canopy which might be replaced (depending on growth rates, longevity, survivorship/mortality, etc.) eventually by an oak-hickory canopy. Such a pattern, if verified by subsequent long-term observation, would corroborate the pattern of cyclical species alternations in the present stand.

Categorization and classification of patterns resulting from the continuous and highly integrated processes which occur during secondary succession/community development in forest ecosystems are of limited direct utility when applied to observations made or data gathered over a few-year time interval. Such generalizations and simplifications of complex, integrated community responses are valuable starting points however in planning subsequent studies. They allow important and testable hypotheses to be formulated regarding mechanisms and causality underlying observed and implied patterns.

LITERATURE CITED

Auclair, A. N. and G. Cottam. 1971. Dynamics of black cherry (*Prunus serotina* Ehrh.) in southern Wisconsin oak forests. Ecol. Monogr. 41:153-177.

Barden, L. S. 1979. Tree replacement in small canopy gaps of a *Tsuga canadensis* forest in the southern Appalachians, Tennessee. Oecologia 44:141-142.

Braun, E. L. 1950. Deciduous Forests of Eastern North America. Hafner Publ. Co., N.Y. (reprint 1964). 596 pp.

Bray, J. R. 1956. A study of mutual occurrence of plant species. Ecology 37:21-28.

Brewer, R. and P. G. Merritt. 1978. Windthrow and tree replacement in a climax beech-maple forest. Oikos 30:149-152.

Buckner, E. and W. McCracken. 1978. Yellow-poplar: A component of climax forests? J. For. 76:421-423.

Connell, J. H. and R. O. Slayter. 1977. Mechanisms of succession in natural communities and their role in community stability and organization. Amer. Natur. 111:1119-1144.

Dew, K. 1980. Comparison of canopy and understory species association patterns in mature Piedmont forests. Unpublished M.S. thesis, Emory Univ., Atlanta, Ga. 61 pp.

Egler, F. E. 1954. Vegetation science concepts. I. Initial floristic composition. A factor in old-field vegetation development. Vegetatio 4:412-417.

Ehrenfeld, J. G. 1980. Understory response to canopy gaps of varying size in a mature oak forest. Bull. Torrey Bot. Club 107:29-41.

Forcier, L. K. 1975. Reproductive strategies and the co-occurence of climax tree species. Science 189:808-809.

Fowells, H. A. 1965. Silvics of Forest Trees of the United States. USDA-Forest Service, Washington, D.C., Agric. Handbook No. 271. 762 pp.

Fox, J. F. 1977. Alternation and coexistence of tree species. Amer. Natur. 111:69-89.

Goff, F. G. 1968. Use of size stratification and differential weighting to measure forest trends. Amer. Midl. Natur. 79:402-418.

Jackson, L. W. R. 1959. Relation of pine forest overstory opening diameter to growth of pine reproduction. Ecology 40:478-480.

Johnson, R. L. and R. M. Krinard. 1976. Hardwood regeneration after seed tree cutting. USDA For. Ser. Res. Paper SO-123. 9 pp.

Jones, E. W. 1945. The structure and reproduction of the virgin forest of the north temperate zone. New Phytol. 44:130-148.

Keever, C. 1953. Present composition of some stands of the former oak-chestnut forest in the southern Blue Ridge Mountains. Ecology 34:44-54.

Mackey, H. E. and N. Sivec. 1973. The present composition of a former oak-chestnut forest in the Allegheny Mountains of western Pennsylvania. Ecology 54:915-919.

March, W. J. and J. N. Skeen. 1976. Global radiation beneath the canopy and in a clearing of a suburban hardwood forest. Agric. Meteorol. 16:321-327.

Marks, P. L. 1974. The role of pin cherry (Prunus pensylvanica L.) in the maintenance of stability in northern hardwood ecosystems. Ecol. Monogr. 44:73-88.

McGee, C. E. and R. M. Hooper. 1975. Regeneration trends 10 years after clearcutting of an Appalachian hardwood stand. USDA-For. Ser. Res. Note SE-227. 3 pp.

Nelson, T. C. 1955. Chestnut replacement in the southern highlands. Ecology 36:352-353.

Oliver, C. D. 1980. Even-aged development of mixed-species stands. J. For. 78:201-203.

Oliver, C. D. and E. P. Stephens. 1977. Reconstruction of a mixed-species forest in central New England. Ecology 58:562-572.

Oosting, H. J. 1942. An ecological analysis of plant communities of Piedmont, North Carolina. Amer. Midl. Natur. 28:1-126.

Skeen, J. N. 1974. Composition and biomass of tree species and maturity estimates of a suburban forest in Georgia. Bull. Torrey Bot. Club 101:160-165.

Skeen, J. N. 1976. Regeneration and survival of woody species in a naturally-created forest opening. Bull. Torrey Bot. Club. 103:259-265.

Skeen, J. N. and W. J. March. 1977. The effect of summer thunderstorms on the near-ground temperature regimen within a suburban forest. J. Tenn. Acad. Sci. 52:95-99.

Skeen, J. N., M. E. B. Carter, and H. L. Ragsdale. 1980. Yellow-poplar: the Piedmont case. Bull. Torrey Bot. Club. 107:1-6.

Smith, A. P. 1973. Stratification of temperate and tropical forests. Amer. Natur. 107:671-683.

Society of American Foresters. 1964. Forest Cover Types of North America (exclusive of Mexico). SAF, Washington, D.C., 67 pp.

Stephenson, S. L. 1974. Ecological composition of some former oak-chestnut communities in West Virginia. Castanea 39:278-286.

Watt, A. S. 1947. Pattern and process in the plant community. J. Ecol. 35:1-22.

Wendel, G. W. 1975. Stump sprout growth and quality of several Appalachian hardwood species after clearcutting. USDA-For. Ser. Res. Paper NE-329. 9 pp.

Wharton, C. H. 1978. The Natural Environments of Georgia. Ga. Dept. Nat. Resources, Atlanta, Ga. 227 pp.

STAND DEVELOPMENT FOLLOWING TWO TYPES OF CLEARCUTTING FOR DEER AND TIMBER PRODUCTION[1]

Jack A. Muncy and Edward Buckner[2]

Abstract. -- One year after harvesting there was no significant difference in the composition and structure of the regeneration that became established following complete (all stems over 6 feet high) and diameter limit (3 inches) clearcuts. Typical pioneer species, such as shortleaf pine and yellow-poplar, were largely absent.

Most of the regeneration was sprouts; old seedlings were of secondary importance and new seedlings comprised only a small portion of the regeneration mix. Species and diameter (or age) were the primary factors affecting sprouting characteristics. Basal and stump sprouts were the predominant sprout types for all size classes; root sprouts were common only for small diameter trees.

Regeneration following complete clearcutting appears to have a better chance for rapid development as the small diameter trees left following diameter limit clearcutting are responding to release and will soon compete strongly with new regeneration. Many leave-trees in the diameter limit treatment were damaged during logging and most are undesirable species for timber production.

Logging slash may protect regeneration from deer browsing. Deer exclosures will permit evaluation of their influence in future inventories.

INTRODUCTION[3]

A primary concern in developing timber cutting prescriptions for wildlife management units is maintaining a high-quality wildlife habitat in balance with secondary multiple use objectives. Effective management requires an understanding of the effects of various cultural techniques (cutting methods, prescribed fire, etc.) on the composition, quality, quantity, and availability (over time) of wildlife food and cover and on secondary multiple use objectives, such as timber production.

Clearcutting of hardwoods has been widely used to maintain browse within reach of deer (Odocileus virginianus). Regrowth following clearcutting generally provides abundant deer browse for three to four years after which stem terminals grow beyond the reach of deer and stand closure results in the natural pruning of lower limbs. Ten to 12 years after clearcutting there is generally little browse available. Burning two to three years after clearcutting may prolong the period of browse availability.

This study was the second (validation) phase of a project designed to develop a computer model simulating the composition and development of forest stands following clearcutting. Its purpose was to provide field documentation of the effects of complete and diameter limit clearcuts on the composition and structure of regeneration as validation information for an independently derived stand succession computer model developed as Phase I.

STUDY AREA

The Catoosa Wildlife Management Area (CWMA) near Crossville, Tennessee is the largest (80,000 acres) wildlife management unit managed by the Tennessee Wildlife Resources Agency (TWRA). It is managed under the multiple use concept with deer production the primary objective; timber harvesting is secondary.

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[3] This research was sponsored by the Silviculture Laboratory, USDA-Forest Service, Southern Forest Experiment Station, Sewanee, Tennessee.

This part of the Cumberland Plateau comprises the Southwest Section of the Appalachian Plateau Physiographic Province. In Tennessee it contains approximately 3 million acres that are 75 percent forested.

The soils are the well drained Hartsells and Lonewood series which are very strongly to strongly acid throughout all horizons (Elder, 1977). Low soil fertility characterizes both series. The topography is level to gently rolling and the elevation is 1,700 to 1,760 feet. The climate is characterized by cool winters and mild summers, with a monthly mean temperature range from 35 degrees (F) in January to 73 degrees in July and 57 inches annual precipitation.

Oak-dominated forests that best fit the Society of American Foresters (SAF 1964) Type 41-Scarlet Oak (in the Oak-Hickory Type Group) are characteristic of this section of the Cumberland Plateau. Their seral position approaches climax on dry soils. This type has many variants due to the large number of associated species. In the study area these include the dry phase oaks, particularly post, (Quercus stellata Wangenh.), southern red (Quercus falcata Michx.) and black (Quercus velutina Larn.).

Prior to the establishment of the CWMA these stands were logged and periodically burned. American chestnut (Castanea dentata Marsh.) and chinquapin (Castanea pumila Mill.) sprouts occurred in both study areas suggesting the former presence of large trees.

Stand age was approximately 65 years for the dominant canopy trees although several age classes were represented in the heterogenous stand structure. Most of the large trees contained rot due to the frequent fires that characterized this section of the Cumberland Plateau prior to the mid-1950's.

METHODS

Two study areas (each approximately 40 acres in size) were selected as "typical" for upland sites on the CWMA. Principal component analysis (PCA) (Isebrands and Crow 1975) indicated that the two study areas were similar, with understory differences accounting for most of the variation.

On each area the following treatment plots (10 acres) were established: 1) a diameter limit clearcut removing all stems down to 3 inches dbh (following guidelines previously established by the Tennessee Wildlife Resources Agency for this area), 2) a complete clearcut in which all trees over 6 feet high were either harvested or felled, and 3) a control in which there was no cutting. Each of these main treatment plots were subdivide into burned and unburned subplots (5 acres). Subplots are to be burned once regeneration in the cut areas begins to grow out of reach of deer.

On each of the 5-acre subplots, 9 systematically arranged sample points were established providing plot center for concentric plots on which a pre-harvest inventory was made of: 1) me chantable timber (11.0 inches dbh and greater) on 1/5-acre plots, 2) pulpwood (stems between 3.0-10.9 inches dbh) on 1/20-acre plots, 3) sapli (stems between 6 feet high-2.9 inches dbh) on 1/40-acre plots, and 4) regeneration (stems less than 6 feet high) on 1/100-acre plots.

Logging of merchantable timber was accomplis in the fall, winter, and spring of 1978-79. A follow-up operation assured the cutting of all stems greater than 3 inches dbh on the diameter limit clearcut areas, and all stems over 6 feet high on the complete clearcuts. Twenty-four deer and rabbit (Sylvilagus floridanus) exclosure each covering one-fortieth of an acre were erecte to monitor the influence of browsing on regenerat and stand development. After one growing season, a post-harvest inventory was made to characterize the composition and character of the initial stands that developed following cutting. Periodi re-inventories will trace stand development unde the various study conditions.

RESULTS AND DISCUSSION

Since, after one year, there were no statistically significant compositional differences between the stands developing following the two cutting methods, regeneration data for both treatments were combined and a single stand characterized (Table 1).

Regeneration

Regeneration (less than 6 feet high) in the two clearcuts averaged 4,945 stems per acre, of which 35 percent was oak, 34 percent other poten overstory hardwoods, 30 percent understory hardwoods, and 1 percent pine. Of these, 2,754 stem (56 percent) were sprouts (sprout clumps were counted as single stems), 1,295 stems (26 percen were old seedlings (advanced regeneration), and 896 stems (18 percent) were new seedlings.

There was adequate regeneration of species suitable for both timber production and wildlif foods. However, common pioneer species for thi region such as Virginia pine (Pinus virginiana Mill.), shortleaf pine (Pinus echinata Mill.) a yellow-poplar (Liriodendron tulipifera L.) were essentially absent. Except for a few Virginia pines, these trees were not present in the stan harvested. Although Virginia pine was harveste

TABLE 1

REGENERATION ONE YEAR AFTER CLEARCUTTING (BOTH TREATMENTS COMBINED)

Species	Old Seedlings		Sprouts		New Seedlings		Total	
	- - - - - - - - - - Stems per acres (percent) - - - - - - - - - -							
Oaks								
Scarlet	364	(28)	369	(13)	274	(31)	1,007	(20)
Black	117	(9)	183	(7)	74	(8)	374	(8)
Southern Red	35	(3)	97	(4)	71	(8)	203	(4)
Post	32	(2)	56	(2)	13	(1)	100	(2)
White	13	(1)	25	(1)	26	(3)	64	(1)
Hickories								
Pignut	51	(4)	65	(2)	18	(2)	135	(3)
Mockernut	15	(1)	13	(*)	3	(*)	31	(*)
Other Potential Overstory Hardwoods								
Blackgum	99	(8)	572	(21)	106	(12)	776	(16)
Red Maple	357	(28)	174	(6)	117	(13)	647	(13)
Persimmon	17	(1)	29	(1)	4	(*)	50	(1)
Black Locust	14	(1)	31	(1)	3	(*)	47	(1)
Black Cherry	–	( )	1	(*)	–	( )	1	(*)
Understory Hardwoods (including shrubs)								
Sassafras	56	(4)	971	(35)	140	(16)	1,167	(24)
Dogwood	69	(5)	92	(3)	39	(4)	200	(4)
Sourwood	11	(1)	43	(2)	3	(*)	57	(1)
Serviceberry	10	(1)	22	(1)	6	(*)	37	(*)
Chinkapin	4	(*)	8	(*)	–	( )	13	(*)
Am. Holly	6	(*)	–	( )	–	( )	6	(*)
Am. Chestnut	–	( )	3	(*)	–	( )	3	(*)
Pines								
Virginia	24	(2)	–		1	(*)	25	(*)
White	3	(*)	–		–	( )	3	(*)
Totals	1,295	(100)	2,754	(100)	896	(100)	4,945	(100)

*When less than 1 values not recorded.

off both areas there were only 25 seedlings per acre in the regeneration, most of which were present as advanced regeneration. Pioneer species may become more important as seed drifts in from surrounding areas; however, early establishment is generally essential for these species to compete successfully.

Oak.--Scarlet Oak dominated the regeneration with 1,007 seedlings per acre (20 percent) followed by black oak with 374 seedlings per acre (8 percent), southern red oak with 203 seedlings per acre (4 percent), and post oak with 100 seedlings per acre (2 percent). White oak (*Quercus alba* L.) had only 64 seedlings per acre (1 percent). Oaks accounted for 35 percent of the regeneration.

They were represented in all three regeneration classes (old seedling, sprouts, and new seedling), but were most abundant in the sprout class and least frequent as new seedlings. Scarlet oak had 274 new seedlings per acre, the highest such count (16 percent) for the oaks.

Other Potential Overstory Hardwoods. This group accounted for 34 percent of the regeneration. Predominant species were blackgum (*Nyssa sylvatica* Marsh.) with 776 seedlings per acre (16 percent) and red maple (*Acer rubrum* L.) with 647 seedlings per acre (13 percent). Secondary associates were (in the order of decreasing importance) pignut hickory (*Carya glabra* Mill.), persimmon (*Diospyrous virginiana* L.), mockernut hickory (*Carya tomentosa* Nutt.), and black locust (*Robinia pseudoacacia* L.).

Black cherry (Prunus serotina Ehrh.) was rare, averaging only one seedling per acre. These secondary species accounted for only 5 percent of the regeneration.

The predominate regeneration type was sprouts; new seedlings were infrequent for all species. While blackgum and red maple were well represented in all seedling classes, red maple occurred most frequently as old seedlings and blackgum as sprouts. Among the secondary species black cherry occurred only as sprouts while the others were present in low numbers in all regeneration classes.

Understory Hardwoods (including shrubs). This group comprised 30 percent of the regeneration. Sassafras (Sassafras albidum (Nutt.) Nees) was dominant with 1,167 seedlings per acre (24 percent); secondary species included dogwood (Cornus florida L.)(4 percent), sourwood (Oxydendrum arboreum (L.) DC.) (1 percent) and serviceberry (Amelanchier laevis Wieg.), chinkapin, American holly (Ilex opaca Ait.) and American chestnut combined for the remaining 1 percent.

Sprouts were the common regeneration type for all species except American holly which occurred only as old seedlings. New seedlings were infrequent for all species. While sassafras regeneration was largely from sprouts (Table 1), most came from small diameter stems (Figure 1).

Pine. Virginia pine accounted for 0.4 percent of the new regeneration (25 seedlings per acre) and white pine (Pinus strobus L.) accounted for 0.1 percent (3 seedlings per acre). Most were old seedlings; new seedlings for both species averaged only one per acre. Almost all old seedlings had poor form due to deer browsing.

Sprouting Characteristics

Although a significant difference in composition between treatments was not found, differences in the number of sprouts were apparent. Since most of the sprouting was from smaller stems there was less sprouting on the diameter limit clearcuts as most small stems were left standing.

Species and diameter (or age) were primary determinants of the sprouting characteristics of cut trees. Small sapling-sized trees were the most prolific sprouters with almost all cut trees up to 5 inches dbh producing sprouts; however, a high proportion of these small diameter trees were shrubs. The diameter (breast height) below which species generally sprout when cut is shown in Figure 1. Sprouting vigor declines rapidly with increasing diameter (and age). The stage of most prolific sprouting ordinarily ends before the trees become effective seed producers.

Stump and basal sprouts (root collar area) were most vigorous suggesting that stumps should be cut as low as possible for well-formed coppice regeneration. Trees cut during the dormant period

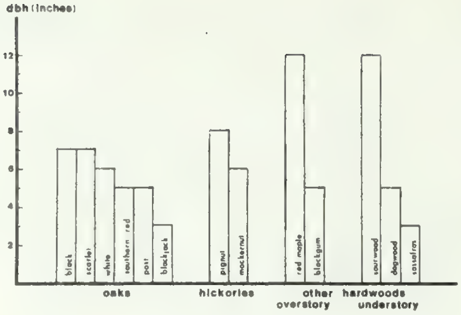

Figure 1. Diameter (bh) below which over 70 percent of the cut stems sprouted.

sprouted more vigorously than those cut during late spring and summer. This may be due to carbohydrate reserves in the roots that are at a minimum in the spring immediately after the formation of the new leaves and shoots, build up over the summer, and are highest during the winter.

Uncut Trees

The two clearcutting methods resulted in a wide difference in the residual stands. In the diameter limit clearcut there were 197 residual trees per acre over 6 feet high, 80 of which were damaged in the cutting operation.

The small, open crowns of residual trees had not responded to release after one year and did not compete seriously with the developing stand. However, as their crowns fill out and larger root systems develop, they will compete more intensel with regeneration while that on the complete clearcut will be free to continue rapid development.

These residual trees do not have the potent for developing into a quality timber stand as ma were damaged during the cutting operation and most were not desirable timber species. However they are now dominants in the developing stand. While some will provide den cover and mast they will have a negative value for deer product

Sassafras, dogwood, and sourwood accounted for the majority of the leave-trees that were no damaged. These are understory species and will decline in importance as potential overstory hardwoods overtop them.

Browsing

Leopold (1950) reported that severe browsi pressure is exerted during the critical winter months when the food supply is low. Continuous activity in the study areas (harvesting, exclosu construction, and follow-up treatment applicati during this period probably discouraged deer from browsing in the study area. While deer browsing was evident, deer exclosures were completed so late in the growing season that statistical testing of its impact was considered inappropriate.

Logging Slash

Zones of heavy accumulation of logging slash were created where trees were felled away from haul roads and skid trails. Joranson and Kuenzel (1940) reported that slash disposal is not a problem in the coppice method because the sprouts will come up through fairly dense cover and any reduction in the number of sprouts causes the growth to be concentrated on fewer stems. This suggests that site preparation is not required for coppice regeneration, as sprouts can come through logging slash and sprouting is not influenced by the condition of the forest floor.

Although a large percentage of the advanced regeneration in the diameter limit cut was damaged, buried, or crushed by slash, thin loose layers of slash may be of real benefit to young seedlings by protecting them from extreme temperatures, desiccation, and browsing animals. Grisez (1960) surveyed reproduction in logging slash 5 years after a heavy cutting in a black cherry-beech-maple stand. He found substantially larger numbers of preferred species in slash piles than in the intervening openings. In areas where deer browsing limits reproduction, hardwood slash may serve as a deterrent to browsing.

IN CONCLUSION

The findings of this study reflect stand characteristics one year after cutting. Periodic reinventory will be necessary to determine the effects of these cultural techniques over time and provide the validation needed to fine-tune the Phase I simulation model.

LITERATURE CITED

Elder, J. A.
1977. The soil series of the Catoosa area. Unpublished report, Tennessee Valley Authority, Norris, Tennessee. 22 pp.

Grisez, T. J.
1960. Slash helps protect seedlings from deer browsing. J. Forestry. 58:385-387.

Isebrands, J. G., and T. R. Crow.
1975. USDA Forest Service North Central For. Exp. Sta. Gen. Tech. Rep. NC-17.

Joranson, P. N., and J. G. Knenzel.
1940. Control of sprouting from white oak stumps. J. Forestry. 38:735-737.

Leopold, A. S.
1950. Deer in relation to plant successions. J. Forestry. 47:675-678.

Society of American Foresters.
1964. Forest cover types of North America. Soc. Amer. For. Washington. 67 pp.

DESIGNING FOREST OPENINGS FOR THE GROUP SELECTION METHOD[1/]

Burnell C. Fischer[2/]

Abstract.--SHADOS, a computer model for calculation of light received by small openings, was used to compare opening sizes commonly recommended for group selection. Square openings 0.5 to 4.0 tree heights receive 5% and 86% of full sunlight. North slopes and elongated openings of the same area received reduced light levels. Foresters practicing selection silviculture need to better understand opening size and shape relationships.

INTRODUCTION

Forest openings whether man-made or natural contain certain unique microclimates which are distinctly different from those found either under a continuous forest canopy or in large clearcuts. Because of the trend towards reducing the size of clearcuts to "patch clearcuts" and the increased use of the group selection reproduction method in hardwood silviculture, particularly on nonindustrial, private woodlands, there is a need to better understand how to design forest openings so that closer control can be obtained in management situations.

Even-aged (-sized) Silviculture

A silviculture system is the process whereby forest stands are tended, harvested, and replaced, resulting in a stand of distinctive form. A reproduction method is the procedure that results in the development of a new stand (Smith 1962). In uneven-aged silviculture, there is one system - selection. The two recognized reproduction methods of selection silviculture are single tree and group selection. In both of these methods, the stand is manipulated for a continuous high-forest cover, recurring regeneration of desired species, and the orderly growth and development of trees through a range of age or size classes to provide a sustained yield of forest products. Managed, uneven-aged (-sized) stands are characte ized by trees of many sizes intermingled singly or in groups. Mature trees are harvested singly or in small groups, and the process of regenerati desirable species occurs either continuously or at each harvest. Harvests usually include thinnings and cultural treatments to promote growth and to maintain or enhance stand structure (Gibbs 1978).

The range of regeneration cutting methods in use today differ from one another primarily in their effect on light exposure. Both single tree and group selection harvesting create gaps or openings in the overstory canopy which allow some additional sunlight to reach the understory and/c the forest floor. Clearcutting permits maximal levels of sunlight to reach the ground.

Several silvicultural guides, although stre ing the desirability of even-aged silviculture, do provide limited space for describing how owne ship objectives may require some type of partial cutting or selection silviculture (Roach and Gingrich 1968; Leak, et.al. 1969). Generally, the practitioner is cautioned not to attempt sin tree selection but to cut openings from a fracti of an acre to 2 acres in size. These opening si appear to be the best compromise between the "desire" for selection silviculture and the grow conditions required to have at least a portion o the regeneration composition be intolerant and mid-tolerant species.

Computer Analysis of Opening Light Dynamics

A series of studies at Purdue University ha been undertaken to evaluate and produce practica computer models of light energy distribution within small forest openings (Fischer and Merrit 1978). A computer model for calculation of ligh

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1/ Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

2/ Assistant Professor of Silviculture, Department of Forestry and Natural Resources, Purdue University, West Lafayette, Indiana 47907 received by small forest openings, entitled SHADOS, was developed (Fischer 1974; Fischer and Merritt 1978). The model predicts the sun-shadow pattern on the floor of forest openings of any size, shape, aspect, and slope and for any latitude and selected time and day. Heights of trees surrounding the opening must also be specified. The computer model can also calculate the direct, diffuse, and total light energy received at any point on an opening floor for instantaneous or integrated time periods. In addition, an option of on-line graphing of sun-shadow patterns is available to the user.

Direct radiation is calculated by determining whether a given point on the opening floor is in the shade or sun for each sample time. When a point is found to be in the sun, the instantaneous direct beam solar radiation for that particular time is calculated and assumed for the selected time interval. A summation of direct energy is then derived for the total time period of interest.

Using SHADOS, I simulated direct solar radiation for clear, sunny days (atmospheric transmission coefficient 0.60), monthly during the growing season (April 12 - August 30) for square openings for a latitude of 40°14'00". Table 1 shows the effect of aspect, slope and opening size on the percent of direct solar radiation received by the floor of square forest openings. All percentages in this paper are based upon averages for the entire opening floor and are expressed as a percent of direct solar radiation received by an open horizontal surface of equivalent area.

For simplicity, only two aspects, 0° (north) and 180° (south), are depicted. Slopes of 0, 15 and 30 degrees give a total of five aspect/slope combinations for each of four opening sizes ranging from 0.5 to 4 tree heights (H).

Table 1 demonstrates the large increases in direct solar radiation received as opening size increases from 0.5 to 4 tree heights. Also, the effect of a north aspect on the percent of direct solar radiation received by openings is apparent with all size openings.

It is important to realize that the opening sizes shown in Table 1 are in the range commonly recommended for group selection. I have shown opening sizes in terms of tree heights because the relationship in regular openings of opening-diameter to perimeter tree-height determines the light energy distribution on the opening floor. The area for the four openings illustrated in Table 1 would be 0.03, 0.11, 0.45 and 1.80 acres for a perimeter tree height of 70 feet. For a perimeter tree height of 90 feet, corresponding areas would be 0.05, 0.19, 0.74 and 2.98 acres.

Table 1.--Effect of aspect, slope and opening size on the percent of direct solar radiation received by the floor of square openings.

Aspect/Slope (deg./deg.)	Opening size in tree heights 0.5	1.0	2.0	4.0
		percent		
0/30	1	15	34	57
0/15	4	19	47	74
0/0	5	24	56	86
180/15	5	30	66	89
180/30	12	37	66	87

It is interesting that Daniel, et.al. (1979) recommend a maximum size of one to two tree heights for group openings so as not to lose the site protection by the surrounding trees. On the other hand Marquis (1965) has discussed controlling light with small clearcuttings not to exceed 1 acre in size. Merritt's (1979) conclusion that openings must have at least a 50% fully open, unprotected microclimate to qualify as a clearcut appears a more reasonable silvicultural definition. This corresponds to openings of at least 4-6H (Fischer 1979).

To evaluate effect of shape and orientation on opening light dynamics I simulated direct solar radiation as in Table 1 for openings of 1 and 2 tree heights (aspect/slope, $0^{o}/0^{o}$). For each of these opening sizes I maintained the same opening floor area by halving the dimensions in one direction and doubling the dimensions in the other. Then, I repeated the process a second time. This results in a square 1H opening first being transformed to a 1/2H by 2H opening and then to a 1/4H by 4H opening. These openings were oriented with the long axis east-west and then north-south. The percent of direct solar radiation received by the floor of each opening shape and orientation was calculated. These results are shown in Table 2.

The comparative decrease in light energy received at the opening floor particularly in the openings that were 16:1, is quite large. These results demonstrate that square or circular openings maximize direct light levels and elongated openings of the same size and area receive less direct light.

Of course, both orientation and width affect the amount and pattern of sunlight. Narrow openings (strips) that are oriented east-west receive more direct sunlight early in the morning and late in the afternoon but are relatively protected (shaded) during mid day. North-south openings receive most direct light around noon when solar intensity is greatest and are more shaded earlier and later in the day. This explains the higher value in the narrow 1/4 by 4H north-south oriented opening.

Table 2.--Effect of shape and orientation on the percent of direct solar radiation received by the floor of 1 and 2 tree height forest openings.

Opening Dimensions in Tree Heights	Orientation of Long Axis East-West	North-South
	Percent	
0.25 x 4.0	5.1	12.2
0.5 x 2.0	18.6	17.9
1.0 x 1.0	24.3	
0.5 x 8.0	31.3	22.7
1.0 x 4.0	57.0	34.3
2.0 x 2.0	55.6	

Silvicultural Considerations

The wide range in percent direct solar radiation for 0.5H to 4H openings shown in Table 1, and the lower light levels in north facing and elongated openings (Table 2) demonstrate the great variation in opening microclimates within narrow size limits. Thus, the field forester, who is practicing group selection silviculture, must be very precise in choosing and marking groups to achieve his silvicultural objectives.

In the upland Central Hardwood stands of Indiana, as well as in all eastern hardwood forests, high light levels are prerequisite for the growth of the more valuable intolerant species, and apparently necessary for the perpetuation and release of advanced oak regeneration (Fischer 1979). At least 90% of the commercial forest land in the Central Region is in nonindustrial private ownership, usually in small acreages probably averaging less than 40 acres (Merritt 1979). These woodland owners generally "demand" uneven-aged (-sized) silviculture and foresters attempt to provide it through group selection so that the more desirable mid- and intolerants are regenerated. How successful are these foresters?

In a recently completed study (Callahan and Fischer 1980) of 23 selectively harvested woodlands an assessment of the overstory canopy at 264 inventory plot locations in the 23 woodlands clearly showed that openings in the canopy were characteristically small (Table 3). At nearly 90 percent of the plot locations, the canopy openings were less than one tree height in width (about 60-70 feet). In only five percent of the cases were the openings sufficiently large (two to three tree heights in width) to be significant in the stimulation of advanced oak regeneration and other intolerant species. Characteristically these woodlands, as well as many in the Central Region are regenerating primarily to lower-valued tolerants and undesirable species. Clearly, foresters practicing selection silviculture need a better understanding of opening size and shape as related to needs of tree regeneration for sunlight.

Table 3.--Size of openings in the overstory canop above 264 inventory plot locations in 23 Indian woodlands following selection harvesting.

Opening Size[1/] in tree heights	No. of Plots frequency	Frequenc percent
0	188	71.2
0.5	42	15.9
1.0	19	7.2
1.5	2	.8
2.0	8	3.0
2.5	0	0
3.0	5	1.9
Totals	264	100

Conclusions

It is apparent that high light levels are necessary for the growth of both new seedlings and advanced hardwood regeneration and that thes light conditions cannot be achieved by the singl tree selection method. Group selection, however offers the possibility of creating forest openings of sufficient size to attain these high lig levels.

[1/] Opening size is the diameter of the tree canc opening in which the 1/10 acre plot was located. Diameter was estimated in dominant tree height units to the nearest 0.5 tree height.

The light energy received on the floor of a forest opening of any size, shape, aspect and slope can be predicted by a computer model. By incorporating stand characteristics and the desired regeneration layer response with the results of the model, forest openings can be precisely designed to achieve many silvicultural objectives.

LITERATURE CITED

Callahan, J. C. and B. C. Fischer.
1980. Economic and silvicultural potentials of 23 harvested Indiana woodlands. USDA Forest Service Research Paper, North Central Experiment Station. (In Press)

Daniel, T. W., J. A. Helms and F. S. Baker.
1979. Principles of silviculture. Second Edition. McGraw-Hill, Inc., 500 p.

Fischer, B. C.
1979. Managing light in the selection method. p. 54-60. In. Proceedings of the 1979 John S. Wright Forestry Conference, Purdue University, West Lafayette, IN. 132 p.

Fischer, B. C. and C. Merritt.
1978. SHADOS: A computer model to simulate light energy distribution in small forest openings. p. 302-319, Proceedings of the Second Central Hardwood Forest Conference, Purdue University, West Lafayette, IN.

Gibbs, Carter B.
1978. Uneven-aged silviculture and management? Even-aged silviculture and management? Definition and differences. p. 18-24. In. Uneven-aged silviculture and management in the United States. Timber Management Research Service, USDA, Washington, D.C. 234 p.

Leak, W. B., D. S. Soloman and S. M. Filip.
1969. A silvicultural guide for northern hardwoods in the Northeast. USDA Forest Service Research Paper NE-143, 34 p.

Marquis, D. A.
1965. Controlling light in small clearcuttings. USDA Forest Service Research Paper NE-39, 16 p.

Merritt, C.
1979. An overview of oak regeneration problems. p. 1-10. In. Proceedings of the 1979 John S. Wright Forestry Conference, Purdue University, West Lafayette, IN. 132 p.

Roach, B. A. and S. F. Gingrich.
1968. Even-aged silviculture for upland central hardwoods. USDA Forest Service Agriculture Handbook 355, 39 p.

Smith, D. M.
1962. The practice of silviculture. Seventh Edition. John Wiley & Sons, Inc., 578 p.

A COMPARISON OF REPRODUCTION AND GROWTH AND YIELD AFTER 36 YEARS FROM FOUR REPRODUCTION CUTTING METHODS IN LOBLOLLY-SHORTLEAF PINE STANDS [1]

James B. Baker and Paul A. Murphy [2]

Abstract.--Four reproduction cutting methods employed on a good site in second-growth loblolly-shortleaf pine in south Arkansas provided adequate pine regeneration to establish or maintain well stocked stands. During the 36-year study period, seed-tree and diameter-limit cutting methods produced significantly more cubic-foot volume than selection and clearcutting, while clearcutting resulted in significantly less board-foot (Doyle) volume.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980, and to be submitted to the Southern Journal of Applied Forestry.

[2] Authors are Principal Silviculturist and Principal Mensurationist, Southern Forest Experiment Station, U. S. Forest Service, Monticello, Arkansas.

SILVICULTURAL CONSIDERATIONS IN DEVELOPING INTEGRATED SOUTHERN PINE BEETLE MANAGEMENT PROCEDURES[1]

Roger P. Belanger[2]

Abstract.--Silvicultural principles and practices are integrated into the research and development components of a pest management procedure designed to prevent or reduce losses from the southern pine beetle. Research and user needs are identified related to the planning, selection, and implementation of forest protection strategies.

INTRODUCTION

The development, integration, and implementation of strategies and practices to prevent or reduce serious losses from insect and disease pests are new and complex undertakings in southern forestry. Although the definition of integrated pest management (IPM) may differ by organization and individual, the concept generally involves the selection and use of protection activities based on predicted economic, ecological, and sociological consequences (Bottrell 1979). A model structure for forest pest management (fig. 1) shows the research and operations action flow needed to develop an integrated protection plan. This approach has been the framework for the major activities within the Expanded Southern Pine Beetle Research and Applications Program (ESPBRAP) started in 1975. The basic components of IPM--pest population dynamics, forest stand dynamics, treatments, and impact--are closely related to one another. Primary disciplines involved in the developmental process are entomology, pathology, silviculture, mensuration, economics, and management. Previous knowledge has been combined with new technology to provide the data inputs required to structure and sequence the system. This paper describes how silvicultural principles and practices can be incorporated into the research and operations components of IPM procedures designed to prevent or reduce losses from the southern pine beetle (SPB - Dendroctonus frontalis Zimmermann).

The Stand Component

The stand is the basic link between pest population dynamics, impact assessment, and treatment (Waters and Stark 1980). It is also the basic unit of silviculture. An extensive coordinated southwide ESPBRAP effort identified stand conditions associated with SPB attacks and developed systems for ranking the susceptibility of stands to beetle attack. Site conditions, tree species and size classes associated with SPB attacks differ somewhat between the Coastal Plain, the Piedmont, and the Southern Appalachian Mountains (table 1). However, slow radial growth and dense stocking are common characteristics of high-hazard stands.

Hazard ratings indicate where beetle outbreaks are most likely to occur and, if they do, where beetle activity and losses are likely to be greatest. Several rating systems have been developed that provide an evaluation of potential risk. Testing and implementing the ranking systems have been limited to stand, site, and insect conditions associated with selected areas in the geographic subregions.

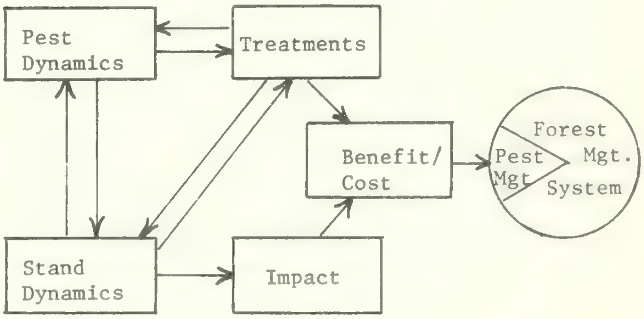

Figure 1.--The structure and sequence of a model integrated pest management system (from Waters and Cowling 1976).

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[2] Principal Silviculturist, USDA Forest Service, South. For. Exp. Stn., Gainesville, Fla.

Table 1.--Characteristics of Natural Stands Susceptible to SPB Attack

Southern Coastal Plain	Piedmont	Southern Appalachians
Densely stocked stands	Well-stocked stands	Densely stocked stands
Large proportion of sawtimber	Small sawtimber	Large proportion of overmature sawtimber
Declining radial growth	Slow radial growth during last 10 years	Slow radial growth
Poorly drained soils and low-lying areas	High percentage of clay in surface and sub-surface soils	Dry, south-facing slopes
High percentage of shortleaf and/or loblolly pine in the stand	High percentage of shortleaf pine in the stand	High percentage of shortleaf and/or pitch pine in the stand

The Southern Coastal Plain.--Natural stands susceptible to beetle attack in the Gulf Coastal Plain are characterized by high stand densities, a large proportion of pine sawtimber and declining radial growth. Outbreaks occur more frequently in stands located on poorly drained, moist sites than on dry and droughty soils. Rating systems have been developed in the Coastal Plain for East Texas (Hicks et al. 1980; Mason 1981), the Kisatchie National Forest in Louisiana (Lorio 1978; Lorio and Sommers 1981), corporate timberlands in Texas, Louisiana, and Mississippi (Kushmaul et al. 1979), and forests in South Arkansas (Ku et al. 1980).

The Southern Appalachians.--Studies in the mountains of Georgia, North Carolina, South Carolina, and Tennessee showed that stands most subject to SPB attack were densely stocked, slow growing, and had a large proportion of overmature pine sawtimber (Belanger et al. 1979; Belanger and Hatchell 1980). Shortleaf pine (*Pinus echinata* Mill.) and pitch pine (*P. rigida* Mill.) were more susceptible to beetle attack than Virginia pine (*P. virginiana* Mill.) and loblolly pine (*P. taeda* L.). The majority of infestations were recorded on south-facing slopes. However, this aspect is where most of the pines occur in the Southern Appalachians.

The Piedmont.--Natural stands susceptible to SPB attack in the Piedmont are well-stocked pine stands with a large percentage of the host component in shortleaf pine, slow radial growth during the last 10 years, and a high clay content in surface and subsurface soils (Belanger et al. 1977; Maki et al. 1978; unpublished). Two systems have been developed for ranking the susceptibility of natural stands to SPB attack in the upper Piedmont of Georgia. The first is a predictive equation that includes variables easily measured or often contained in existing inventories (Belanger et al. 1981); the second is a system designed for use in the field by service foresters (Belanger and Price 1979).

In summary, unhealthy stands are highly susceptible to attack by the SPB. This familiar and basic principle applies regardless of region or pine type.

The Treatment Component

Several silvicultural and direct control options are available that will prevent or reduce losses from the SPB (fig. 2). Silvicultural practices can lower the susceptibility of stands to beetle attack by increasing stand vigor. Direct control practices are used to prevent additional losses in stands that have been attacked by the beetle.

Preventative Silviculture

Proper silvicultural treatment of forest stands is an essential element in developing strategies to achieve long-term success in reducing losses from the SPB. Intermediate cuttings and regeneration methods provide the means to produce environmental and biological conditions unfavorable to the attack, spread, and population growth of this forest pest. No "standard" recommendation will apply to all situations. Each forest condition and locality presents different management problems; each might require a different combination of methods to increase resistance to SPB attack. General

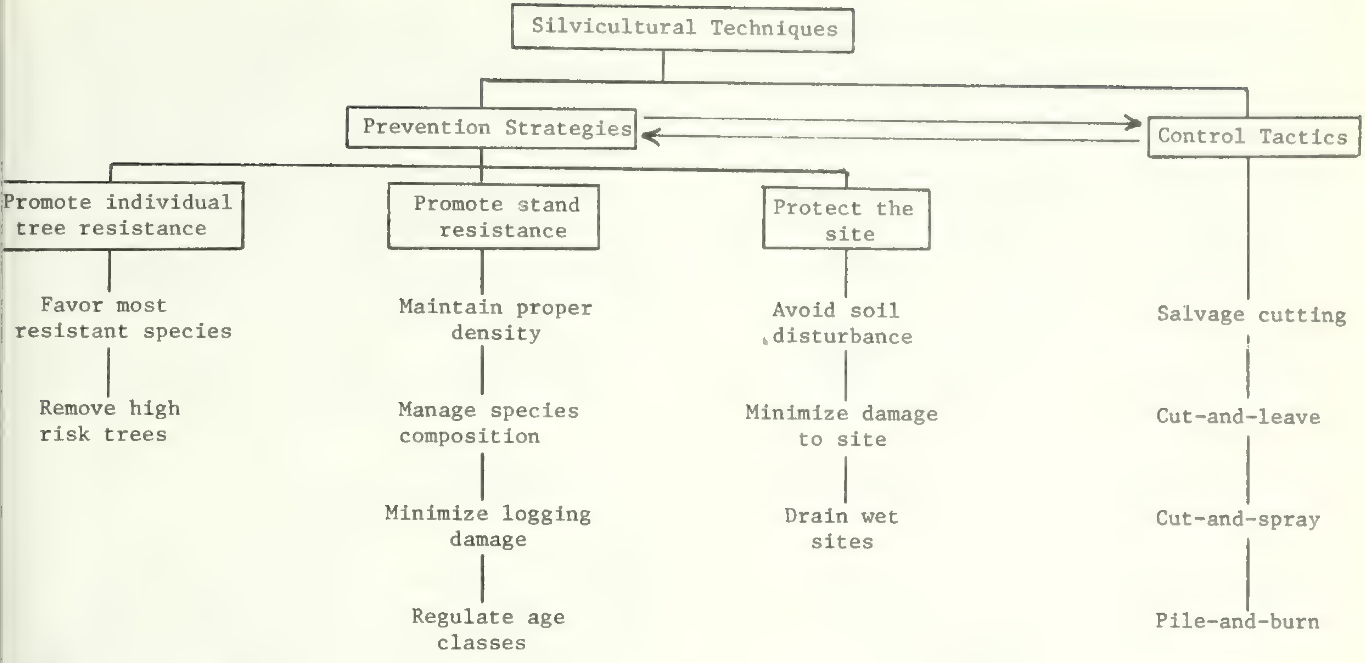

Figure 2.--Silvicultural guidelines to reduce losses from the southern pine beetle.

guidelines have been developed based on past and ESPBRAP supported research (Bennett 1968, 1971; Hedden 1978; Hicks et al. 1979; Belanger 1980; Belanger and Malac 1980) to reduce the potential for losses. These include:

- Favor tree species that are most resistant to SPB attack (table 2) and best suited to the site (Coyne and Lott 1976; Hodges et al. 1977, 1979; Belanger et al. 1979, 1981; Ku et al. 1980).
- Salvage trees damaged by lightning, wind, ice, and other destructive agents. Pines struck by lightning offer a favorable environment for the SPB and several species of *Ips* beetles. (Hodges and Pickard 1971). Stands with trees damaged by wind, ice, and hail are more susceptible than undisturbed stands.
- Thin to reduce competition, remove slow growing trees which are subject to SPB

Table 2.--The Susceptibility of Pines to SPB Attack for Major Geographic Regions of the South

Levels of susceptibility	Geographic Region		
	Coastal Plain	Piedmont	Southern Appalachian
Most resistant	Slash Longleaf	Virginia Loblolly	Virginia Eastern white
Most susceptible	Shortleaf Loblolly	Shortleaf	Shortleaf Pitch

attack (Haines et al. 1976; Ku et al. 1976), and stimulate vigor in young stands. Degree of thinning is determined by the intensity of management, the kind of product desired, available markets, and natural conditions specific to each location. Basal areas of 80 to 100 ft^2/acre are recommended to reduce the hazard ratings of stands (Hicks et al. 1979; Belanger 1980; Belanger and Malac 1980).

* Manage a mixture of pine and hardwood species. The SPB prefers pure pine stands. A mixture of pine and hardwood species reduces the potential for spot incidence and growth (Belanger et al. 1979; Hedden and Billings 1979).

* Use harvesting systems that minimize logging damage. Logging activity has a tendency to increase SPB attack (Porterfield and Rowell 1980). Mechanical injury to above- and below-ground portion of residual trees also provides attack courts for the black turpentine beetle (BTB- Dendroctonus terebrans Olivier) and Ips spp.

* Regenerate mature and overmature stands. Susceptibility of stands to SPB attack increases with age throughout most of the South (Lorio 1978; Belanger et al. 1979; Coster and Searcy 1980).

* Protect the site as much as possible. High-hazard sites in the Piedmont are characterized by a high percentage of clays in the surface and subsurface soil horizons (Belanger et al. 1981). Infestations in the Coastal Plain occur more frequently on wet and water logged sites than on well-drained sites (Lorio and Hodges 1971; Belanger et al. 1977; Hicks et al. 1979). Abuse of these delicate sites will only increase SPB problems in the future.

Control Practices

Infested trees can be salvaged to utilize merchantable material or simply felled into openings and exposed to maximum sunlight. Brood mortality can be increased by high inner-bark temperatures (Hodges and Thatcher 1976). Sanitation cuttings remove damaged, infested, and high-risk trees to prevent the spread and proliferation of the SPB. If salvage removal or cut-and-leave are used, and fresh attacks are present, a buffer strip of uninfested pines should be cut around the active head of a spreading spot to interrupt the advance of the beetle (Billings and Pace 1979). As a rule of thumb, width of the buffer strip should be roughly equal to average tree height in the spot (Billings 1980).

The forest manager may elect to treat a stand to modify beetle activity, or he may risk beetle infestations, rely on intensive surveillance for detection, assess potential damage to the stand, and assign (or not assign) treatments accordingly. Decisions are made on a case-by-case basis. Size of the stand, value of the stand, existing markets, and management objectives all enter into evaluating alternatives. Information from the insect dynamics and impact components should also be considered when deciding what SPB strategies will best benefit resource objectives.

Insect Dynamics

SPB populations typically rise and fall over time. Unfortunately, these cycles are irregular and unpredictable. The silviculturist and forest manager are at a disadvantage when beetle populations are high. Any preference by the SPB for particular stand conditions are masked by the indiscriminant development and spread of infestations associated with epidemic beetle populations (Belanger et al. 1981; Mason 1981). Infestations can develop and persist even in relatively sparse stands if levels of beetle activity and rates of attack are high (Hedden and Billings 1979). Direct control practices during these conditions are emphasized out of necessity.

Silvicultural activities related to forest pest management are generally neglected during periods of low beetle activity. Yet, this is the time when the planning and application of prevention strategies should be greatest. High-hazard stands can be identified and treated to reduce their susceptibility to beetle attack. At this time mill quotas include very little salvage wood and operators are available to conduct intermediate cuttings. Also, endemic "reservoirs" of SPB-infested trees and high-risk trees are removed and more growing space is provided for residual trees. The probability of spot initiation and spread is lowest when insect populations are down. Low-hazard stands can be tended to maintain vigor and rapid growth.

Historical records of SPB activity can be useful to silviculturists and forest managers concerned with protecting forest resources. For example, beetle incidence, spot proliferation, and spot growth during the last three major SPB outbreaks in the Piedmont of Georgia were consistently more severe in some counties than in others. Obviously, prevention and suppression activities should be concentrated in the problem counties. From a research standpoint, we need to determine what the differences are (stand ? site ? climate ?) between areas that historically have been hard-hit and areas that have few beetle problems.

Beetle behavior varies during different seasons of the year. Studies in East Texas showed that beetle populations disperse and initiate multiple-tree infestations primarily during the spring; spot growth replaces spot proliferation as the primary mode of beetle colonization during the summer (Hedden and Billings 1979). Treatment of high-hazard stands can influence the spread of the SPB during most years. Silvicultural practices that promote stand vigor will decrease the probability of beetle attack. Sparse pine stocking will restrict the number of trees being killed once the spot has been initiated. Density of the pine component can be regulated by manipulating stocking levels, making intermediate cuttings, and favoring pine-hardwood stands.

Impact

The responsibility of the silviculturist is to produce and maintain a forest that best fulfills the objectives of the owner (Smith 1962). Traditionally, the primary concern of the silviculturist has been to maximize the production of wood crops. Today the silviculturist is also being asked to answer questions concerning the impact of regeneration methods, intermediate cuttings, and protection strategies on the environment, economy, and people (Stark 1979). The silviculturist is generally not trained to answer these questions and must turn to specialists in other disciplines for help. This, in large part, is what integration is about. Following are examples of how silvicultural practices can impact multiple resource values.

Environmental Impact

Thinning is recommended to reduce stand density and increase stand vigor. The forester must be aware, however, that intermediate cuttings on certain sites can promote infection and spread of annosum root rot (Heterobasidion annosum (Fr.) Bref). Studies have shown a close association between this disease and SPB attack (Alexander et al. 1980). Precautions should be taken to reduce the danger of annosum infection. Intermediate cuttings should be scheduled during summer when fewer H. annosum spores are produced and high temperatures may kill those that are produced. Treating stumps with borax or the antagonistic fungus Peniophora gigantia minimizes spread. Prescribed burning before and after thinning also reduces severity of annosum root rot in the South (Froelich et al. 1978). Stand-site studies have shown no relationship between burning and SPB attack.

Economic Impact

Some forest managers consider intermediate cuttings to prevent SPB attack a "luxury." This may be the case if stands are being managed using short rotations and the primary objective is pulpwood. It may not be the case if you are managing for multiple products under longer rotations.

High-hazard stands often contain quality, sawtimber-size trees. Losses from SPB attack and rapid spread in these high value stands can be enormous. Benefits from prevention and control measures may exceed the costs of treatments if these stands are needed to meet management objectives. Stand growth models for plantations and naturally seeded stands allow simulation of management practices on tree growth (Daniels and Burkhart 1975). The forest manager can use these models to determine which course of action may be best suited to individual stands and ownership objectives.

Sociological Impact

Damage to stands by the SPB can influence the value judgment of people. Studies conducted on the Blue Ridge Parkway in Virginia showed that viewers responded adversely to areas of beetle-killed trees (Buyhoff and Leuschner 1978). SPB damages were also estimated for intensively used recreation sites in East Texas (Leuschner and Young 1978). Onsite damages ranged from $3,500 to $1,204,000 depending on the recreation site, the severity of attack, and whether travel time costs were included. The investigators concluded the potential damage reduction on recreation sites combined with the small area requiring treatment may well justify intensive prevention and/or suppression activities.

IMPLEMENTATION: BARRIERS AND PROGRESS

Some of the technology needed to develop strategies and practices that will reduce losses from the SPB is in hand and being transferred to users. Yet, most resource managers have been reluctant to incorporate this knowledge into their planning, decision making, and operations. What are the silvicultural needs that contribute to this impasse? First and foremost, the manager is looking for convincing evidence that prevention strategies and control practices are effective and efficient in reducing SPB losses. The net effect of recommended practices must produce tangible benefits that contribute to the objectives of management.

There is the question as to where and under what conditions hazard rating systems can be applied. For example, can stand hazard rating models developed in the Piedmont of Georgia during endemic beetle conditions be used to accurately rate the susceptibility of stands in Georgia (or elsewhere) when populations are high? Do hazard rating systems developed for natural stands apply to plantations? Will stands treated to prevent or reduce attacks from the SPB increase or decrease damage from Ips spp. black turpentine beetles, or tree-killing diseases?

Some of the rating systems require variable inputs that are difficult and expensive to obtain. Can these systems be simplified and still provide meaningful information for management decisions? What level of accuracy will users be willing to accept?

Managers have equally long lists of questions related to the other subject matter represented in the components of the proposed SPB system. Perhaps the integration--as envisioned--is too cumbersome, difficult, and rigid to be readily incorporated into resource management systems. The Integrated Pest Management RD&A Program on Bark Beetles of Southern Pines[3] will address some of these questions during the next five years. Meanwhile, managers that are experiencing or wish to avoid severe losses from the SPB may want to examine and include some of what we do know about the beetle in their management programs. Methods for making better control decisions can be strengthened as additional information related to "integrated forest protection" becomes available.

LITERATURE CITED

Alexander, S. A., J. M. Skelly, R. S. Webb, R. R. Bardinelli, and B. Bradford. 1980. Association of Heterobasidion annosum and the southern pine beetle on loblolly pine. Phylopathology 70:510-513.

Belanger, R. P. 1980. Silvicultural guidelines for reducing losses to the southern pine beetle. In The Southern Pine Beetle, p. 165-177. R. C. Thatcher, J. L. Searcy, J. E. Coster, and G. D. Hertel, eds. U.S. Dep. Agric. For. Serv., Tech. Bull. 1631. Comb. For. Pest Res. Develop. Prog., Pineville, La.

Belanger, R. P., and G. E. Hatchell. 1980. The Southern Appalachians. Site, stand, and host characteristics of southern pine beetle infestations. U.S. Dep. Agric. For. Serv., Tech. Bull. 1612. Comb. For. Pest. Res. Develop. Prog., Pineville, La.

Belanger, R. P., G. E. Hatchell, and G. E. Moore. 1977. Soil and stand characteristics related to southern pine beetle infestations: a progress report for Georgia and North Carolina. In Proc. Sixth South. For. Soils Workshop, p. 99-107. U.S. Dep. Agric. For. Serv., Southeast. Area, State and Private Forestry, Atlanta. (Charleston, S. C., October 1976.)

Belanger, R. P., E. A. Osgood, and G. E. Hatchell. 1979. Stand, soil and site characteristics associated with southern pine beetle infestations in the Southern Appalachians, 7 p. U.S. Dep. Agric. For. Serv., Res. Pap. SE-198. Southeast. For. Exp. Stn., Asheville, N. C.

Belanger, R. P., and B. F. Malac. 1980. Silviculture can reduce losses from the southern pine beetle. USDA Comb. For. Pest Res. Develop. Prog. Agric. Handb. No. 576.

Belanger, R. P., R. L. Porterfield, and C. E. Rowell. 1981. The development and validation of systems for rating the susceptibility of natural stands in the upper Piedmont of Georgia to attack by the southern pine beetle. In Hazard rating systems in forest insect pest management: symposium proceedings. (Athens, Ga., July 1980.) R. L. Hedden and J. L. Searcy, eds. U.S. Dep. Agric. For. Serv., Tech. Bull. ___. South. For. Exp. Stn., New Orleans, La. (In press.)

Belanger, R. P., and T. S. Price. 1979. The susceptible forest in the upper Piedmont. Pest Leaflet developed by the Georgia Forestry Commission, Macon, Ga. and the Southeast. For. Exp. Stn.

Bennett, W. H. 1968. Timber management and southern pine beetle research. For. Farmer 27(9):12-13.

Bennett, W. H. 1971. Silvicultural techniques will help control bark beetles. In Proc., 1971 Southern Regional Technical Conference p. 289-295. Soc. Am. Foresters, Washington, D. C.

Billings, R. F. 1980. "Cut-and-leave" for control of southern pine beetle. For. Farmer 39(10): 6 ff.

Billings, R. F., and H. A. Pace III. 1979. A field guide for ground checking southern pine beetle spots. USDA Comb. For. Pest Res. and Develop. Prog. Agric. Handb. No. 558. 19 p.

Bottrell, Dale R. 1979. Integrated pest management. Council of Environ. Quality, Washington, D. C. 120 p.

---

[3] U.S. Department of Agriculture, Forest Service, Pineville, Louisiana.

Buyhoff, G. J., and W. A. Leuschner. 1978. Estimating psychological disutility from damaged forest stands. For. Sci. 24:424-32.

Coster, J. E., and J. L. Searcy, eds. 1980. Site, stand, and host characteristics of southern pine beetle infestations. U.S. Dep. Agric. For. Serv., Tech. Bull. 1612. Comb. For. Pest Res. Develop. Prog., Pineville, La.

Coyne, J. F., and L. H. Lott. 1976. Toxicity of substances in pine oleoresin to southern pine beetles. J. Ga. Entomol. Soc. 11: 301-305.

Daniels, R. F., and H. E. Burkhart. 1975. Simulation of individual tree growth and stand development in managed loblolly pine plantations. Div. of For. and Wildlife Resources, Va. Polytech. Inst. and State Univ. Publ. FWS-5-75, 69 p.

Froelich, R. C., C. S. Hodges, Jr., and S. S. Sackett. 1978. Prescribed burning reduces severity of annosus root rot in the South. For. Sci. 24:93-100.

Haines, L. W., S. G. Haines, and F. T. Liles, Jr. 1976. Effects of fertilization on susceptibility of loblolly pine to the southern pine beetle. 55 p. N. C. State Univ. School For., Fert. Coop. Tech. Rept. 58. North Carolina State University, Raleigh, N. C.

Hedden, R. L. 1978. The need for intensive forest management to reduce southern pine beetle activity in East Texas. South. J. Appl. For. 2:19-22.

Hedden, R. L., and R. F. Billings. 1979. Southern pine beetle: Factors influencing the growth and decline of summer infestations in East Texas. For. Sci. 25:547-556.

Hicks, R. R., Jr., J. E. Howard, K. G. Watterston, and J. E. Coster. 1980. Rating forest stand susceptibility to southern pine beetle in East Texas. For. Ecology and Management 2:269-283.

Hicks, R. R., Jr., J. E. Coster, and K. G. Watterston. 1979. Reducing southern pine beetle risks through proper management planning. For. Farmer 38(7):ff.

Hodges, J. D., W. N. Elam, and W. F. Watson. 1977. Physical properties of the oleoresin system of the four major southern pines. Can. J. For. Res. 7:520-525.

Hodges, J. D., W. N. Elam, W. F. Watson, and T. E. Nebeker. 1979. Oleoresin characteristics and susceptibility of four southern pines to southern pine beetle (Coleoptera: Scolytidae) attacks. Can. Entomol. 111:889-896.

Hodges, J. D., and L. S. Pickard. 1971. Lightning in the ecology of the southern pine beetle, Dendroctonus frontalis (Coleoptera: Scolytidae). Can. Entomol. 103:44-51.

Hodges, J. D., and R. C. Thatcher. 1976. Southern pine beetle survival in trees felled by the cut and top-cut and leave method. U.S. Dep. Agric. For. Serv., Res. Note SO-219, 5 p. South. For. Exp. Stn., New Orleans, La.

Ku, T. T., J. M. Sweeney, and V. B. Shelburne. 1976. Preliminary evaluation of site and stand characteristics associated with southern pine beetle infestations in Arkansas. Ark. Farm Res. 25:2.

Ku, T. T., J. M. Sweeney, and V. B. Shelburne. 1980. Site and stand conditions associated with southern pine beetle outbreaks in Arkansas--hazard rating system. So. J. Appl. For. 4:103-106.

Kushmaul, R. J., M. D. Cain, C. E. Rowell, and R. L. Porterfield. 1979. Stand and site conditions related to southern pine beetle susceptibility. For. Sci. 25:656-664.

Lorio, P. L., Jr. 1978. Developing stand risk classes for the southern pine beetle. USDA For. Serv., Res. Pap. SO-144, 9 p. South. For. Exp. Stn., New Orleans, La.

Lorio, P. L., Jr., and J. D. Hodges. 1971. Microrelief, soil water regime, and loblolly pine growth on a wet, mounded site. Soil Sci. Soc. Am. Proc. 35:795-800.

Lorio, P. L., Jr., and R. A. Sommers. 1981. Stand risk classification for the southern pine beetle with available resource data. In Hazard rating systems in forest insect pest management: symposium proceedings. (Athens, Ga., July 1980.) R. L. Hedden and J. L. Searcy, eds. U.S. Dep. Agric. For. Serv., Tech. Bull. ___. South. For. Exp. Stn., New Orleans, La. (In press.)

Maki, T. E., D. W. Hazel, and J. R. Hall. 1978. An exploration of a few major factors, including prolonged flooding, that appear to be associated with southern pine beetle epidemics. 146 p. ESPBRAP Final Report (unpublished).

Mason, G. N. 1981. Development and verification of stand susceptibility ratings for southern pine beetle in East Texas: An aerial photo approach. In Hazard rating systems in forest insect pest management: symposium proceedings. (Athens, Ga., July 1980.)

R. L. Hedden and J. L. Searcy, eds. U.S. Dep. Agric. For. Serv., Tech. Bull. ___. South. For. Exp. Stn., New Orleans, La.

Porterfield, R. L., and E. E. Rowell. 1980. Characteristics of southern pine beetle infestations southwide. In Site, stand, and host characteristics of southern pine beetle infestations. J. E. Coster and J. L. Searcy, eds., U.S. Dep. Agric. For. Serv., Tech. Bull. 1612. Comb. For. Pest Res. Develop. Prog., Pineville, La.

Smith, D. M. 1962. The practice of silviculture. 578 p. John Wiley & Sons, Inc., N. Y.

Stark, R. W. 1979. The concept of impact in integrated pest management. In For. Entomol. Sel. Pap. 15th Int. Congr. Entomol., Washington, D. C., August 1976. W. E. Waters, ed., p. 110-116. U.S. For. Serv. Gen. Tech. Rep. WO-8. 174.

Waters, W. E., and E. B. Cowling. 1976. Integrated forest pest management: a silvicultural necessity. In Integrated Pest Management, J. L. Apple, R. F. Smith, eds. p. 149-77. New York: Plenum. 200 p.

Waters, W. E., and R. W. Stark. 1980. Forest pest management: concept and reality. Ann. Rev. Entomol. 1980. 25:479-509.

SILVICULTURAL CONSIDERATIONS FOR MANAGEMENT OF SLASH PINE IN LOWER COASTAL PLAIN WETLANDS[1/]

C. A. Hollis, R. F. Fisher and W. L. Beers, Jr.[2/]

Abstract.--Portions of the coastal lowland provinces of the Lower Coastal Plains are potentially productive and manageable sites if proper consideration is given to the biological needs of slash pine and to the constraints imposed by the site itself and BMP guidelines. Most of these sites require some surface water management for access, seedling survival and tree growth. Our studies show that most water quality problems are related to suspended particulates generated by activities on or adjacent to roads. However, such impacts are of short duration and virtually all evidence of site disturbance disappears within the first year. Thus, opportunities exist for scheduling of silvicultural activities to minimize water quality impact.

Most of these sites are deficient in phosphorus and require fertilization to insure adequate stocking and early height growth. Current evidence indicates that choice of fertilization and timing of applications may substantially reduce water quality impact and improve effectiveness of this operation.

Substantial limitations to tree growth appear to be related to high water table restrictions on root development. Although, partly confounded by nutrient immobilization in the high organic matter fraction of the soil and losses to run off, preliminary evidence suggests that survival, root volume, stem diameter and height growth of young seedlings is proportional to depth of the oxygenated zone of the rhizosphere. Also, opportunities for improving survival and effectiveness of fertilization with mycorrhizally inoculated planting stock appear evident.

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SILVICULTURAL OPTIONS QUANTIFIED: (1-1) SILVICULTURE

Frank W. Woods[2]

A method for quantifying silvicultural options, called (1-1) silviculture, is presented. The notation for expressing (1-1) harvest cuts is revealed. Inclusion of intermediate cuts, their intensities, and grouping effects are shown to be the next necessary development.

INTRODUCTION

Forestry in the United States, as well as throughout the entire world, has been strongly influenced by methods and practices developed in Germany during the 19th century. So strong have been the traditions, that there have been practically no efforts either to examine their basic underlying philosophy or to evaluate their fitness for contemporary needs. This is a tribute to the validity and utility of the silvicultural systems themselves, and a rebuke to those who have accepted the status quo as, "good enough for me." The fact is that the systems have been conceived independently to meet needs as they arose. As a consequence, there is no progressive flow from one to the other and it is not possible to use quantitative differentiation as the basis for selecting one or the other. Such decisions have been, and are today, subjective rather than objective. In the past we have justified this stance by saying, "After all, silviculture is part art and only part science."

There has been only one flurry of activity in which anything remotely resembling the approach proposed here has been investigated. Usher, an English worker, was active in the late sixties (1966, 1967, 1969) and Bosch (1971) shortly thereafter. Neither the most recent German silviculture text (Mayer 1977) or American (Smith 1962) indicate a need for a new trend. In an overview of probable silvicultural changes in the future by Smith (1972) and more recently by Florence (1978), there is still no indication that quantification of silvicultural options would, could, or should emerge.

This attitude cannot long continue. Decision-making is now constrained by so many variables and qualifications that in the future it will be possible to make rational silvicultural choices only with computer-based assistance. Forest managers have, for many years, used tools such as linear programming, capital budgeting, and marginal analysis. Harvest scheduling and multiple use tradeoffs can be readily resolved by use of these techniques. But once a decision is made to pursue and optimize a particular set of goals, the choice of silvicultural methods becomes highly subjective.

For the purposes at hand I have concerned myself only with the nomenclature of harvest cuts in a new approach to silvicultural management, called (1-1) silviculture. The intermediate cuts, and the techniques for arriving at the optimal solution for any desired set of needs will be considered in a future paper.

OBJECTIVES

The goals of the project reported here are to:

(1) develop a notation which will describe any segment from a continuum of possible harvest cuts;

(2) produce subscript which will describe intermediate and harvest cuts; and

(3) produce a subscript which will describe how trees should be grouped in a forest stand.

THE RATIONALE

The harvest cut is the prime determinant factor in (1-1) silviculture, and will be the only operation considered in this paper. It culminates the total increment period (TIP) and may be interrupted by intermediate cuttings with cutting cycles of whatever length best serves a particular need. In this respect it is not different from some of the systems already in use.

The concept of the rotation is not propagated in this system because it is largely a myth. For a single-aged, single-species stand, a rotation length of sorts can be based on a combination of economic and biological factors. But mitigating against even the most perfect of selection and even-aged forests are fire, insect attacks, road construction, air pollution, and other factors which require the early removal of immature trees, and leaving trees which must exceed maturity in order to sustain yield.

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[1] Paper presented at the Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-8, 1980.

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Even though the (1-1) system is a continuum, it has six easily recognizable phases. At one extreme is never-cut silviculture (Fig. 1). The hard-core silviculturist may argue as he has in the past, that without cutting there can be no silviculture. However, since the decision to cut or not-to-cut is a management option, never-cut is as valid as any other alternative. For the preservation of natural and wilderness area, unique kinds of habitats, and wild gene pools that might be destroyed or decimated by tree cutting, it may be the only tenable choice. The species composition of the system must be extremely shade-tolerant if reproduction is to be consistent over long periods of time.

The next category of silvicultural systems includes a continuum of selection-cuts characterized by the fact that stocking is never allowed to reach the zero (0) level. Figures 2, 3 and 4 illustrate selection cutting, with Figure 2 closely related to traditional high-forest selection. The age distribution of trees in Figure 4, and the time-sequence of basal area removal aproaches that which we would find under a shelterwood system. Since any forest stand managed under selection silviculture (1-1) is always stocked, the species which lend themselves to partial-cut necessarily must be at least moderately shade-tolerant.

Figure 5 represents N-A (never-cut and always-cut) silviculture, which results when a mature forest stand is clearcut and left to grow to maturity once again. Because commercial forests are seldom allowed to grow to maturity, it represents a theoretical rather than actual management alternative. Absentee ownership, with periodic clearcutting can produce this pattern.

Figure 6, 7 and 8 illustrate clearcut silviculture in which the stand is periodically clearcut, but never allowed to reach 100% of its growth potential. Figure 6 illustrates a phase similar to the sequence in which pulpwood is frequently produced. Maximum water yield (Figure 7) and wildlife browse and shelter (Figure 8) might be provided by other phases of clearcutting. Species used in this type of silviculture, usually will be intolerant of shade.

Figure 9 illustrates always-cut silviculture, in which all trees are cut at least once each year to maintain a treeless condition. Power line rights-of-way, roadside vistas, and rights-of-way along highways are examples. Here, again, is a silvicultural choice which can be dictated by special conditions and pressures, and which some forest managers might argue--is not true silviculture. Yet, the decisions regarding its use must be made using the same criteria used in which other options are chosen, which is the basis of silvicultural management.

Figure 10 and 11 illustrate S-C (selection-clearcut) silviculture, which combines the features of total and partial cutting. Stocking is never allowed either reach 100% or to drop to 0%. The age distribution of the traditional shelterwood system bears a resemblance to that of Figure 10.

To quantify these options is not difficult. Numerically, we have one number, always positive, which describes the lowest point which stocking is ever allowed to reach. A second number, always negative, describes the highest point that stocking is ever allowed to reach. To express any cutting option therefore requires the use of two numbers, hence the name of the system, (1-1) silviculture. Its value lies in its capacity to quantify the total range of cutting options in such a manner as to present a continuum of choices which are subject to objective decision making. A few examples will help to explain the notation.

In Figure 1, never-cut silviculture is shown to have a value of (0-1), a value which never changes because stocking is always 100%. The percent value, with which all phases are described are divided by 100 to produce numbers which are more manageable when placed in a matrix for "number crunching." Hence, all values will be between $^+1$ and $^-1$.

In Figure 2, the selection option depicted has a value of (.75 - 0), but it can range from (.01 - 0) to (.99 - 0), in the same manner that clearcut silviculture can vary from (0 - .01) to (0 - .99). N-A silviculture (Fig. 5) always has a value of (0-0), because it is a hybrid of never-cut and always-cut silviculture.

S-C silviculture is illustrated in Figures 10 and 11. For this option, stocking is never allowed to reach either 100 or 0 percent. Figure 10 illustrates (50-20) while Figure 11 illustrates (25-25) silviculture.

A steady state stand with less than full stocking can be expressed. Figure 12 provides an example of (.75 - .25) silviculture, which is only one of many possibilities.

Note that it is not possible to have a stand for which the maximum allowable is greater than the minimal allowable growth. Therefore, a (.75 - .30) or a (.50 - .55) stand is not possible.

There are other aspects of the system that need consideration. We must develop the notation for stand information, the "Y" values if you wish, which will express

(1) rotation length,
(2) the timing and intensity of intermediate cuts,
(3) grouping effects, and
(4) any other information about stand structure that is necessary for stand manipulation.

The notation must be derivable by calculation and not merely a qualitative symbol. It will be acceptable, initially, to develop a notation which can be applied to a single stand of trees; however, it must ultimately be developed to express forest conditions, responding to both biological and economic inputs.

The notation for the silvicultural option, which itself is a model, must not be confused with the multi-criterion decision-making model which shapes it.

Even though the system of silvicultural alternatives presented here is in the infancy of its development, it offers a new and unique opportunity for quantifying silvicultural alternatives.

LITERATURE CITED

Bosch, C. A
1971. Redwoods: A Population Model. Science 192:345-349.

Florence, R. G.
1978. The Silvicultural Decision. Forest Ecology and Management 1:293-306.

Mayer, H.
1977. Silviculture on a Sociological-Ecological Basis. Gustav Fischer Verlag. Stuttgart, German Federal Republic.

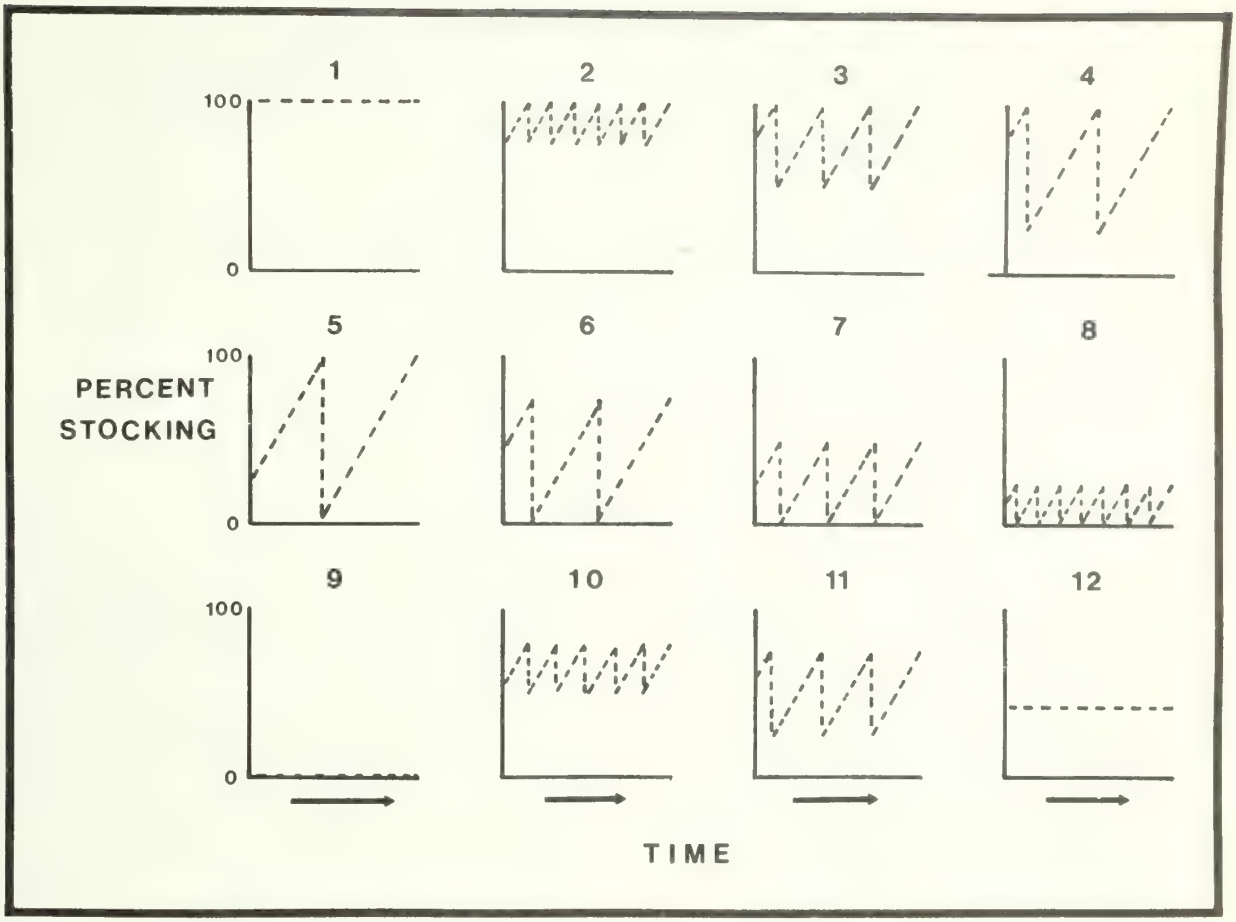
Smith, D. M.
1962. The Practice of Silviculture. John Wiley and Sons. New York, NY.

Smith, D. M.
1972. The Continuing Evolution of Silvicultural Practice. J. For. 70:89-92.

Usher, M. B.
1966. A Matrix Approach to the Management of Renewable Resources, with Special Reference to Selection Forests. J. Appl. Ecol. 3:355-367.

Usher, M. B.
1967. A Structure For Selection Forests. Third Student Forestry Symposium, Edinburgh, pp. 6-8.

Usher, M. B.
1969. A Matrix Model For Forest Management. Biometrics 25:309-315.



Figures 1-12. -- Silviculture (1-1) yields an infinite number of possibilities for harvest cuts. Each of the twelve possibilities illustrated have been discussed in the text.

MINIMUM STOCKING LEVELS REQUIRED FOR SUCCESSFUL MANAGEMENT OF UNEVEN-AGED LOBLOLLY-SHORTLEAF PINE STANDS [1]

B. F. McLemore [2]

Abstract.--Loblolly-shortleaf pine stands on medium and good sites in south Arkansas were cut to stocking levels of 10, 20, 30, 40, and 50 percent, based on a tree-area ratio stocking equation. Residual stems ranged from seedlings to 12 inches dbh and were distributed with a Q-factor of about 1.2. Future measurements will determine recovery rates and minimum stocking levels necessary for successful rehabilitation and management.

INTRODUCTION

In the South, 73 percent (140 million acres) of the commercial forest land is fragmented among more than 1 million private, nonindustrial owners. The average net annual growth of timber on these lands is about one-half the minimum potential of 76 cubic feet/acre/year. Yet these are the forests that must produce a major portion of the predicted twofold increase in demand on southern timberlands by the year 2000. Because need for improving the private landowners' timber production is so urgent, the National Forest Management Act of 1976 and RPA's Renewable Resources Program for 1977-2000 charged the Forest Service with developing alternatives to even-aged management and management systems suitable for private nonindustrial landowners.

Several studies have indicated that uneven-aged management may suit the nonindustrial landowner's objectives better than the intensive even-aged management practiced by most Federal, State, and industrial land managers. A major problem in placing private land under management is the poor condition, or low stocking levels, often found on this land.

Research on the Crossett Experimental Forest has demonstrated that forest properties having as little as 38 ft.^{2} basal area, or 2,000 bd.ft./acre (Doyle) sawlog volume, can be quickly rehabilitated. However, many private ownerships today have stands with stocking levels below 2,000 bd.ft./acre. The question arises, then, as to how poorly stocked a stand may be and subsequently recover after being placed under management. Two studies in south Arkansas were designed to answer this question.

METHODS

Measurement of Stocking

A prerequisite for these studies was development of a means for measuring stocking levels. Stocking, or density, may be expressed in absolute measures which express the density on an area basis. Relative density is based upon a standard. For these studies, density as defined by the tree-area ratio is used (Chisman and Schumacher, 1940). This technique is based upon the assumption that the ground area occupied by a tree is related to dbh by a second-degree parabola. Since the density of stocking is determined by the total of the growing spaces of the individual trees the space utilized on a per-acre basis can be expressed by the general formula:

$$Y = aN + b\Sigma D + c\Sigma D^2$$

where Y is the tree-area ratio or growing space in milacres, N is the number of trees per acre, and D is dbh in inches. This technique provides a measure of density readily usable for uneven-aged stands and is largely independent of age or site index. Chisman and Schumacher used data from

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USDA Misc. Pub. 50 (1929) to derive an equation for so-called "normal" stands of southern pine. Their formula predicts 213 twelve-inch trees, 709 six-inch trees, or 7,067 one-inch trees for 100 percent stocking. These figures were considered too high, so it was decided to follow criteria outlined in the U.S. Forest Service Handbook. The following tabulation shows the density standard in terms of trees per acre, by size class, required for 100 percent stocking:

DBH In.	Trees/Acre No.	DBH In.	Trees/Acre No.
Seedlings	600	16	72
2	560	18	60
4	460	20	51
6	340	22	42
8	240	24	36
10	155	26	31
12	115	28	27
14	90	30	24

Using data in the above tabulation, a formula was fitted to give estimates of the tree-area ratio. In deriving the formula, the dbh of seedlings was considered as 0.0, and midpoints of 1-inch diameter classes were used. The fitted equation, based on the above criteria, was:

$$\text{Tree-area ratio} = 1.6667 + 0.0404D + 0.0434D^2$$

This formula was used for the following studies.

Study Installation

One of the studies was installed on uneven-aged loblolly-shortleaf pine-hardwood stands in Ashley County, Arkansas. Site index for loblolly pine is about 95 feet at age 50. A second study was installed in uneven-aged stands in Nevada and Ouachita counties. Site index for loblolly in this study is about 80 feet. There were fewer hardwoods and underbrush on the Nevada-Ouachita County plots than on the Ashley County plots, probably because of the lower site index.

Stocking levels of 10, 20, 30, 40, and 50 percent were established on square, 1-acre plots, with one-half acre interior measurement plots. Following a preliminary inventory of the study areas, all trees larger than 12 inches dbh were logged from plots during the dormant 1979-80 season. Trees in the smaller dbh classes were subsequently removed until the prescribed stocking level was reached. Remaining trees ranged from 12 inches dbh to seedlings and were selected for uniformity of distribution. An effort was also made to select adequate numbers of stems in each 1-inch diameter class to approximate a Q-factor of 1.2 to 1.3. Theoretical and actual numbers of stems on two study plots (10 and 50 percent) are shown in table 1.

All hardwoods were injected with Tordon 101 in the spring of 1980. The only future management practice anticipated other than hardwood control will be fire protection. Pines reproduced on buffer strips will be allowed to remain, but reproduction on the interior measurement plots will be removed at periodic intervals. Thus, future determinations of stocking levels will take into account only those trees growing on plots when the studies were installed.

Stocking levels, based on the aforementioned tree area ratio, will be determined after 2 and 5 years. Increases in stocking levels will be determined for all plots after each of these periods. Regression analyses will be used to predict stocking after a specified interval, based on initial stocking; percent stocking after the specified interval will be plotted over initial stocking.

Results of these studies should tell how poorly stocked a stand may be and subsequently recover after being placed under management.

LITERATURE CITED

Chisman, H. H. and F. X. Schumacher.
1940. On the tree-area ratio and certain of its applications. Jour. For. 38: 311-317.

U.S. Department of Agriculture.
1929. Volume, yield, and stand tables for second-growth southern pines. Misc. Pub. No. 50.

Table 1.--Theoretical and actual numbers of stems per acre for two representative study plots with 10 and 50 percent stocking.

	50 % Stocking		10 % Stocking	
Dia. Class	Theoret.[1]	Actual[2]	Theoret.[1]	Actual[3]
Inches	No.	No.	No.	No.
Seedlings	48	34	10	12
1	36	20	7	8
2	28	34	6	6
3	22	44	4	2
4	17	16	3	2
5	13	6	3	–
6	10	10	2	–
7	8	10	2	–
8	6	8	1	2
9	4	6	–	2
10	3	4	1	2
11	3	–	–	–
12	2	2	1	2
Total	200	194	40	38

1/ Q-factor of 1.30

2/ Q-factor of 1.26

3/ Q-factor of 1.14

REGULATION OF UNEVEN-AGED LOBLOLLY-SHORTLEAF PINE FORESTS [1]

Robert M. Farrar [2]

Abstract.--Briefly reviews regulation of loblolly-shortleaf pine forests managed under the selection system. Presents two alternative techniques of regulation with some advantages and disadvantages of both. Reports the current effort on regulation research at the Monticello/Crossett Project.

Historically, the selection system has had its ups and downs in this country; and, with few notable exceptions, it has never received the interest given even-aged systems. Perhaps this is because the majority of our most economically important timber types are principally composed of more or less intolerant species and generally well-suited to even-aged silvicultural systems, which in turn may be more efficient for large scale operations. However, there are probably few timber species in the country that cannot be managed under some form of the selection system--including longleaf pine with cyclical burning. But, the process might not be as efficient for some particularly intolerant species as an even-aged system. Past research has shown that the loblolly-shortleaf pine type can be managed rather easily under a selection system. Some form of the selection system may provide an attractive alternative for the non-industrial landowner who possesses few acres, wants to manage his existing stand to obtain reasonable returns in his lifetime, and is unable or unwilling to incur large capital costs associated with certain even-aged management techniques.

Currently, the main drawbacks to selection management seem to be (1) a general unawareness or misconception of the system, (2) vague perceptions of the system as a threat to established policies and operations, and (3) some truly inherent problems regarding: (a) the need for more elaborate inventory details, (b) possible dis-genic effects from mis-application, and (c) perceived difficulties in application of certain area-wide treatments such as prescribed burning. The first drawback, unfamiliarity, can be overcome by reference to good silviculture and management texts (i.e., Smith 1962, Davis 1966) and current literature, and through information exchange with foresters who have effectively practiced the system The second, variance with established operations, should not exist at all because we need to have a full complement of alternative silvicultural and management techniques at our disposal if we are to do justice to our clients and ourselves as professionals. The last group of problems is real but each can be minimized.

DEFINITIONS PERTAINING TO UNEVEN-AGED MANAGEMENT

A few working definitions for this paper's purpose are:

Regulated forest = one where age and/or size classes are represented and growing such that nearly equal periodic yields of desired products are obtained. It may be composed of even-aged stands, uneven-aged stands or both.

Uneven-aged stand = one that contains 3 or more distinct age (size) classes. In practice it is a stand that exhibits a d.b.h. distribution tending towards a "reverse-J" in shape rather than the mound-shaped curve typical of an even-aged stand. It has no start or end point in time.

Balanced uneven-aged stand = one whose d.b.h distribution closely follows a negative exponentia probability density function (reverse-J). The rat of numbers of trees in succeeding d.b.h. classes is a constant (called Q); $N_i/N_{i+1}=Q$.

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[1] Presented at the Southern Silvicultural Research Conference, Atlanta, GA., Nov. 6-7, 1980.

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The exponential p.d.f. is: $f(x) = re^{-r(x)}$ where x = d.b.h. and $Q = e^{rw}$ where w = d.b.h. class width.

The functional form is: $N_i = e^{b_0} e^{b_1(D_i)}$ or $\ln(N_i) = b_0+b_1(D_i)$ where N_i & D_i = number of trees in ith d.b.h. class and $Q = e^{b_i w}$.

Irregular uneven-aged stand = one whose d.b.h. distribution does not closely follow a negative exponential distribution (the Q is not a constant).

Selection system = any silvicultural program aimed at the creation or maintenance of uneven-aged stands.

Selection method = Activities employed for the regeneration of uneven-aged stands. There are several recognized modifications of the selection method: single tree = removal of 1 or few trees for regeneration

group = removal of small patches of trees

strip = similar to strip shelterwood or clearcut

Dauerwald = similar to single tree but no thought given to regeneration

diameter-limit = removal of all trees in and/or above a specified diameter

"economic" selection or "selective cutting" = not a valid method = high-grading

Selection and even-aged systems can be viewed as a closed continuum, i.e., single tree selection can grade into irregular shelterwood, while group selection can approach patch clearcutting. The key distinction is related to area-wise age distribution and record-keeping. For example, if records on tree age (or size) are kept on a tree to tree basis, then the selection system is indicated. If records on tree age (or size) are maintained on an area basis, then an even-aged system is probably being used.

PAST

A history and status report of selection management in this country can be found in the proceedings of a workshop conducted by the Forest Service (1978). A few points brought out at that workshop should be emphasized. The French forester de Liocourt observed that the number of trees in successive d.b.h. classes in an uneven-aged forest tended to decrease in a smooth geometric progression and this progression was apparently stable through time (Meyer 1952). In other words, Q tended to be a constant with time. A number of foresters have made contributions to uneven-aged forest management in various parts of this country. Meyer and Stephenson (1943) noted that the d.b.h. distributions of virgin northern hardwood forests in Pennsylvania tended to have a constant Q and that the structures were also apparently stable through time. Pearson (1950) employed a variation of the selection system in the management of ponderosa pine in the Southwest. Several workers in the U.S. Forest Service's Northeastern Station territory have applied the selection system to various forest types on an experimental basis. They have significantly contributed methods for inventorying and objectively describing and prescribing the structure for selection stands (Leak 1963, 1964, 1965; Trimble et al. 1974; Trimble and Smith 1976; Marquis 1978). Several Western workers have discussed applications and modifications of these techniques in certain coniferous types (Alexander and Edminster 1977 a & b, Hann and Bare 1979). In the South, the most notable contributors to selection management have been Reynolds (1959, 1969), working with loblolly-shortleaf pine stands in southeastern Arkansas, and Brender (1973), working with loblolly pine in the Georgia Piedmont.

This discussion deals with data and derived functions from selection-managed stands in southeastern Arkansas and the application of regulation techniques employed by Reynolds in the Southern Station and suggested by Northeastern Station research.

PRESENT

In uneven-aged management, the cutting cycle replaces the even-aged rotation as an operating control. If a 10-year cutting cycle and an annual cut are desired, the property is divided into 10 equally productive areas and one area is cut each year. Stands are not classified by average age or tree size but by d.b.h. distribution and volume (stand and stock table) and species composition. At our present stage of research at Monticello/Crossett we consider that we have essentially one species--pine--composed principally of loblolly with a minority of shortleaf (about 1/3 of the volume). So, we deal with the pine stand and stock table in regulation activities.

We presently have one operable technique for regulation with which we have had experience--plus some associated local volume prediction and projection equations which allow us to look at various options. This technique is essentially regulation through volume control in the sawtimber component of the stands using a "guiding d.b.h. limit". Briefly, it works as follows: First, you need an inventory by d.b.h. classes and a local or other volume-defining function to generate an observed stand and stock table. Then you decide upon a cutting cycle, how much volume your stand should have at the end of the cycle, and at what rate the stand is expected to grow. For example, if 7000 fbm (Doyle) volume is desired at the end of a 5-year cutting cycle, and the stand is expected to grow at a 6% compound rate, then the residual stand volume is calculated as $7000/(1.06)^5$ or

5231 fbm. If the stand presently has, say, 9952 fbm, the cut is 4721 fbm (9952-5231). A volume of 1769 fbm (7000-5231) should be restored by expected growth in 5 years to result in 7000 fbm standing at the end of that period. A stand containing about 7000 fbm (Doyle), 1400 cubic feet in sawtimber, 2000 merchantable cubic feet, and 75 square feet of basal area is considered by Reynolds [1] to be a general or working optimum at the end of a cutting cycle for south Arkansas and north Louisiana. If the stand initially contains less volume, the cut should be proportionally less to allow for an increase in stocking.

Once the cut volume is determined, volumes are accumulated by d.b.h. class, starting with the largest, until a volume equal to the proposed cut is reached (see table 1). The d.b.h. class where this volume is reached is the "guiding d.b.h. limit" (g.d.l.). The general plan is to cut all trees with d.b.h. equal to or larger than the g.d.l. until the allowable cut is reached. In practice, however, larger trees are left if they are growing well and less desirable smaller trees are substituted. The principal objective is to keep the sawtimber component producing at a good rate. The sub-sawtimber component is not regulated but thinned according to silvicultural need. Silvicultural experience is very valuable in this activity if a sufficient ingrowth reservoir is to be maintained to supply future harvests. No particular attention is paid to regeneration because, in this area, loblolly seeds prolifically and normal cutting and logging disturbance provides adequate space and seedbed requirements--if hardwoods are kept under control. This system closely resembles the classical Dauerwald system of Europe where regeneration received no consideration. In actual practice however, attempting to apply a selection system without some provision for regeneration is like attempting to develop a perpetual motion machine--it is impossible. Periodic regeneration is the necessary basic input that sustains the system.

In order to facilitate prediction of volume growth responses from differing density and cutting cycle regimes, we have developed a system of cubic-foot volume prediction and projection functions (Murphy and Farrar 1980) from long-term studies of regulation at Crossett. The equation system consists of a stand volume predictor and a basal area projector using initial basal area and elapsed time as the input variables and is based on the technique of Moser and Hall (1969). Examples of how this equation system can be used are illustrated in Figures 1 and 2. In the first example, a 3-, 6-, or 9-year cutting cycle is employed with the aim of having the same basal area (or volume) at the end of each cycle. In each case, the stand will have grown back to a density level of 75 square feet of basal area during the interval between harvests. The second example illustrates cutting to a constant basal area (60 square feet) on a 3-, 6-, or 9-year cutting cycle. Table 2 shows the periodic annual increment (p.a.i.) from these exercises over an 18-year period and suggests that little difference can be attributed to cutting cycle length for these examples. Reynolds' (1969) results from maintenance of these cutting cycles for about 30 years on a total of 24 forty-acre compartments supports the same trend.

Table 1.--Example of cut volume determination in a selection stand regulated by "volume-guiding diameter limit" (per acre).

DBH	No. Trees	Merch. Vol.	Board-foot Volume		
	--before cut--		before cut	cumul.cut	after cut
(in.)		(ft^3)	--------(fbm,Doyle)----------		
4	17.1	9			
5	15.6	28			
6	13.2	45			
7	10.0	54			
8	8.5	67			
9	5.6	60			
10	6.0	84	169		169
11	6.7	119	265		265
12	5.9	129	329		329
13	4.3	114	329		329
14	6.1	195	631		631
15	4.0	149	533		533
16	5.3	230	898		898
17	4.5	224	944		944
18	3.2	180	809		809
19[1]	3.5	219	1047	4721	327
20	1.3	94	474	4001	
21	1.6	125	663	3527	
22	1.2	103	573	2864	
23	1.1	100	582	2291	
24	0.9	96	577	1709	
25	0.1	15	93	1132	
26	0.1	16	104	1039	
27	0.3	34	231	935	
28	0.3	36	255	704	
29	0.3	38	281	449	
30	0.0	0	0	168	
31	0.1	21	168	168	
	126.8	2584	9952	4721	5231

[1] guiding d.b.h. limit

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[1] R. R. Reynolds, personal communication, 1979

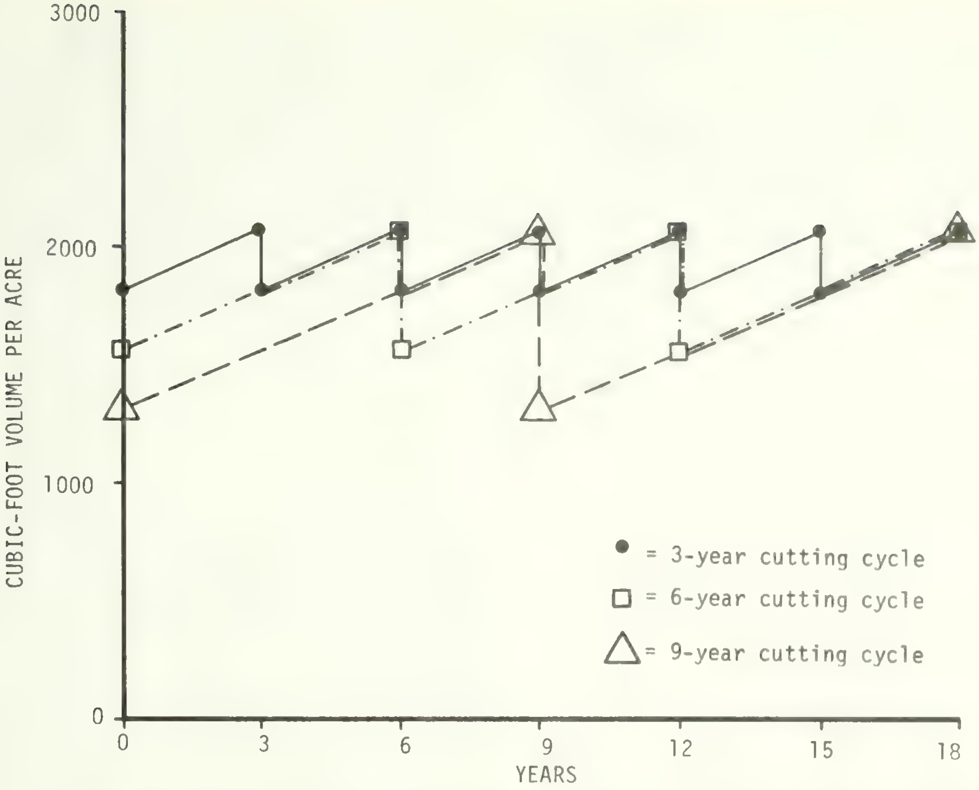

Figure 1.--Predicted stand volumes and removals for loblolly-shortleaf selection stands managed under three cutting cycles, 75 sq. ft. final basal area, SI=90 class.

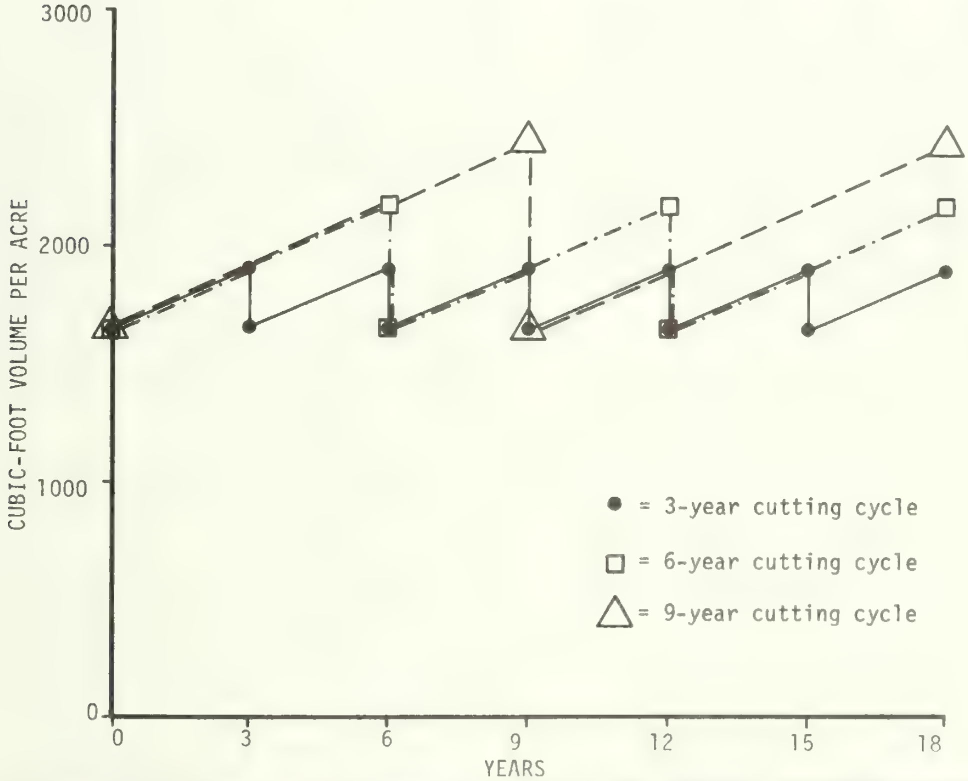

Figure 2.--Predicted stand volumes and removals for loblolly-shortleaf selection stands managed under three cutting cycles, 60 sq. ft. initial basal area, SI=90 class.

Table 2.--Observed and predicted Periodic Annual Increment (P.A.I.) for selection stands of loblolly-shortleaf managed under 3-, 6-, and 9-year cutting cycles, SI=90 class.

Cutting Cycle	Observed (Reynolds 1969)		Predicted			
			Constant 75 Final BA		Constant 60 Initial BA	
(years)	Period (years)	P.A.I. (ft.^{3})	Period (years)	P.A.I. (ft.^{3})	Period (years)	P.A.I. (ft.^{3})
3	27	85.7	18	87.7	18	85.0
6	24	84.5	18	85.7	18	87.0
9	21.4	82.0	18	83.2	18	88.3

Note that the equation system allows simulation of many more regulation schemes than those shown (i.e., increasing or decreasing basal area, varying the cutting cycle within a regime, etc.). Our next step here with this system is to extend it to sawtimber volume prediction and projection and to site indices other than the 90 class.

FUTURE

Experience suggests that the "volume-g.d.l." regulation technique will allow us to adequately regulate selection stands principally for sawtimber volume production for considerable periods of time. Simplicity is its greatest virtue. As long as conditions are similar to those studied at Crossett, our stand basal area and cubic-foot equation system will allow us to predict the initial and final volumes for a considerable array of conditions and anticipated improvements in the system should greatly extend its utility.

However, a few problems remain. One is lack of objectivity in prescribing the structure of the residual stand, particularly the sub-sawtimber component, and another is predicting the size-class distribution of volume in the future structure. The "volume-g.d.l." technique, including the stand basal area and volume predictors, has little predictive ability regarding stand and stock tables. We think for both problems we have a single solution that will provide interim guidelines for regulation. It is employment of the NE Station "basal area-maximum d.b.h.-Q" or BDQ technique for objectively prescribing a residual structure for a selection stand. The elements of BDQ are: the residual basal area (B) that you desire, the maximum tree dbh (D) that you elect to leave, and the ratio (Q) between the numbers of trees in succeeding d.b.h. classes that you select. If you know these three factors and have a volume-defining function, you can generate a stand and stock table for any combination of these 3 factors. The software is easy to develop for computers, including programmable hand-held models. However, computer capability is not at all necessary to employ BDQ (see Marquis 1978).

Starting with an observed stand and stock table from an inventory (table 3), you can generate a target residual structure using the BDQ technique (after Marquis 1978). Basically, this entails distributing the desired residual basal area between specified minimum and maximum d.b.h. classes according to a Q. Table 4 shows a target stand and stock table generated for a B=60, D=22, Q=1.155 and figure 3 shows the d.b.h. distributions. By subtracting the target from the inventory you then know rather precisely how many trees are to be cut and left in each d.b.h. class. If basal area is lacking in some classes you can leave extra basal area in smaller classes. All you have to do is find the trees; cut the worst and leave the best in each class. This is a great advantage for foresters who might like to apply the selection system but do not have experience with it. In field application, the objectivity of this technique is the principal improvement over the "volume-g.d.l." technique where considerable subjectivity is employed in treating the sub-sawtimber component. Also, the entire stand is regulated rather than just one component and this is important if area is to be efficiently utilized and ingrowth reservoirs maintained. Given a reasonably good choice of B, D, and Q, you have an objective means of prescribing the residual stand and the cut. You have some assurance that you have created a reasonably good residual structure for a selection stand even if you have not had extensive experience with selection systems.

This does not mean that we are home free. At present, all we have is circumstantial evidence of the utility of the BDQ technique. As far as I know, it has not been tested rigorously in southern pine stands. However, we do have a good starting point. From the historical records of selection system research, we know that the Q for 1-inch classes hovers around 1.2 (figure 4) for the Crossett stands. This is particularly encouraging because these stands were not regulated by BDQ and residual densities and maximum diameters were not constant within a cutting cycle. We also have evidence as to what the residual basal area (B) should be for cutting cycles of 3 to 10 years for conditions near eynolds' working optimum. Further, we can also elect a maximum d.b.h. (D) that (in conjunction ith B, Q, and estimated B and D growth) will enerate initial and final structures that closely pproximate Reynolds' optimum basal area and olumes (Tables 4 and 5, Figure 5). Obviously, he next step is to experimentally regulate a eries of stands by BDQ and determine the response f basal area, maximum d.b.h., and Q over time. e have initiated research toward this end and ill soon have 66 stands experimentally regulated nder BDQ (table 6). We are confident we can redict future basal areas, and maximum d.b.h. should be predictable from increment cores or, better, from stand parameters and elapsed time. Hopefully, an established Q will essentially remain constant over time but, if not, it should change in a fashion predictable by stand parameters and elapsed time. Given all this plus a tree height predictor and a volume-defining function (i.e., integrated taper function), we then have the components of a stand and stock table predictor and projector for the regulation of selection stands of loblolly-shortleaf that are managed using BDQ.

able 3.--An observed stand and stock table for a selection stand of loblolly-shortleaf, SI=90 class.

```
     Type of inventory: BEFORE-CUT                    INVENTORY SUMMARY
     Compartment: SELECTION 2                  SOUTHERN FOREST EXPERIMENT STATION
     Study: CUT METHODS                             FWU-SO-1117, MONTICELLO
     Species; LOB-SHORT
     Date: APR.79
     Acreage:  7.5

**********+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

 DBH       TPA      BA A      MERCV     SAWCV     TOPCV     DOYLE    INT/4    SCRIB

                                    PER ACRE

   1      0.00      0.00       0.0       0.0       0.0         0        0        0
   2      0.00      0.00       0.0       0.0       0.0         0        0        0
   3      0.00      0.00       0.0       0.0       0.0         0        0        0
   4     17.07      1.49       8.7       0.0       0.0         0        0        0
   5     15.60      2.13      27.7       0.0       0.0         0        0        0
   6     13.20      2.59      45.0       0.0       0.0         0        0        0
   7     10.00      2.67      54.4       0.0       0.0         0        0        0
   8      8.53      2.98      67.3       0.0       0.0         0        0        0
   9      5.60      2.47      60.2       0.0       0.0         0        0        0
  10      6.00      3.27      84.4      40.4      44.0       169      311      160
  11      6.67      4.40     118.8      75.2      43.5       265      535      389
  12      5.87      4.61     129.1      92.4      36.7       329      635      517
  13      4.27      3.93     113.7      86.5      27.2       329      585      500
  14      6.13      6.56     194.6     153.4      41.2       631     1029      903
  15      4.00      4.91     148.9     120.1      28.8       533      804      716
  16      5.33      7.45     230.1     189.1      41.1       898     1270     1140
  17      4.53      7.15     224.2     187.4      36.8       944     1267     1143
  18      3.20      5.65     179.7     152.7      26.9       809     1041      944
  19      3.47      6.83     219.0     189.4      29.6      1047     1305     1188
  20      1.33      2.91      94.0      82.8      11.2       474      577      528
  21      1.60      3.85     125.0     112.2      12.9       663      790      727
  22      1.20      3.17     103.2      94.3       8.9       573      672      622
  23      1.07      3.08     100.3      93.3       7.0       582      673      627
  24       .93      2.93      95.5      90.3       5.2       577      659      618
  25       .13       .45      14.7      14.2        .6        93      105       99
  26       .13       .49      15.9      15.4        .4       104      116      110
  27       .27      1.06      34.0      33.4        .5       231      254      243
  28       .27      1.14      36.2      36.0        .2       255      276      267
  29       .27      1.22      38.7      38.7       0.0       281      298      292
  30      0.00      0.00       0.0       0.0       0.0         0        0        0
  31       .13       .70      21.2      21.2       0.0       168      171      170

        126.80     90.09    2584.2    1918.0     402.9      9952    13373    11902


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Table 4.--A BDQ after-cut target stand and stock table, SI=90 class.

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Type of Inventory :AFTER-CUT TARGET                  TARGET STAND SUMMARY
Compartment Number :SELECTION 2                 SOUTHERN FOREST EXPERIMENT STATION
Study :CUT METHODS                                   PWU-1117, MONTICELLO
Species :LOB-SHORT
Date :APR.79


Minimum DBH:   1
Maximum DBH:   22
Q Ratio : 1.155
DBH Class Width : 1
Exponent on DBH : 1
Basal Area per Acre : 60


*******++++++++++++++++++++++++++++++++++++++++++++++++++++++++*************+++++

DBH      TPA      BA A      MERCV     SAWCV     TOPCV      DOYLE    INT/4    SCRIB

                                   Per Acre

  1     22.66      .12        0.0       0.0       0.0         0        0        0
  2     19.62      .43        0.0       0.0       0.0         0        0        0
  3     16.98      .83        0.0       0.0       0.0         0        0        0
  4     14.71     1.28        7.5       0.0       0.0         0        0        0
  5     12.73     1.74       22.6       0.0       0.0         0        0        0
  6     11.02     2.16       37.6       0.0       0.0         0        0        0
  7      9.54     2.55       51.9       0.0       0.0         0        0        0
  8      8.26     2.88       65.1       0.0       0.0         0        0        0
  9      7.15     3.16       76.9       0.0       0.0         0        0        0
 10      6.19     3.38       87.1      41.7      45.4       174      321      165
 11      5.36     3.54       95.5      60.5      35.0       213      431      313
 12      4.64     3.65      102.2      73.1      29.1       260      503      409
 13      4.02     3.71      107.1      81.5      25.6       310      551      471
 14      3.48     3.72      110.4      87.0      23.4       358      584      512
 15      3.01     3.70      112.2      90.5      21.7       401      606      539
 16      2.61     3.64      112.6      92.5      20.1       439      621      558
 17      2.26     3.56      111.7      93.4      18.4       470      631      570
 18      1.96     3.46      109.8      93.3      16.5       494      636      577
 19      1.69     3.33      107.0      92.5      14.4       511      637      580
 20      1.47     3.20      103.4      91.1      12.3       522      634      580
 21      1.27     3.05       99.2      89.0      10.2       526      627      577
 22      1.10     2.90       94.5      86.3       8.2       525      616      570

       161.75    60.00     1614.5    1072.5     280.3      5204     7398     6421


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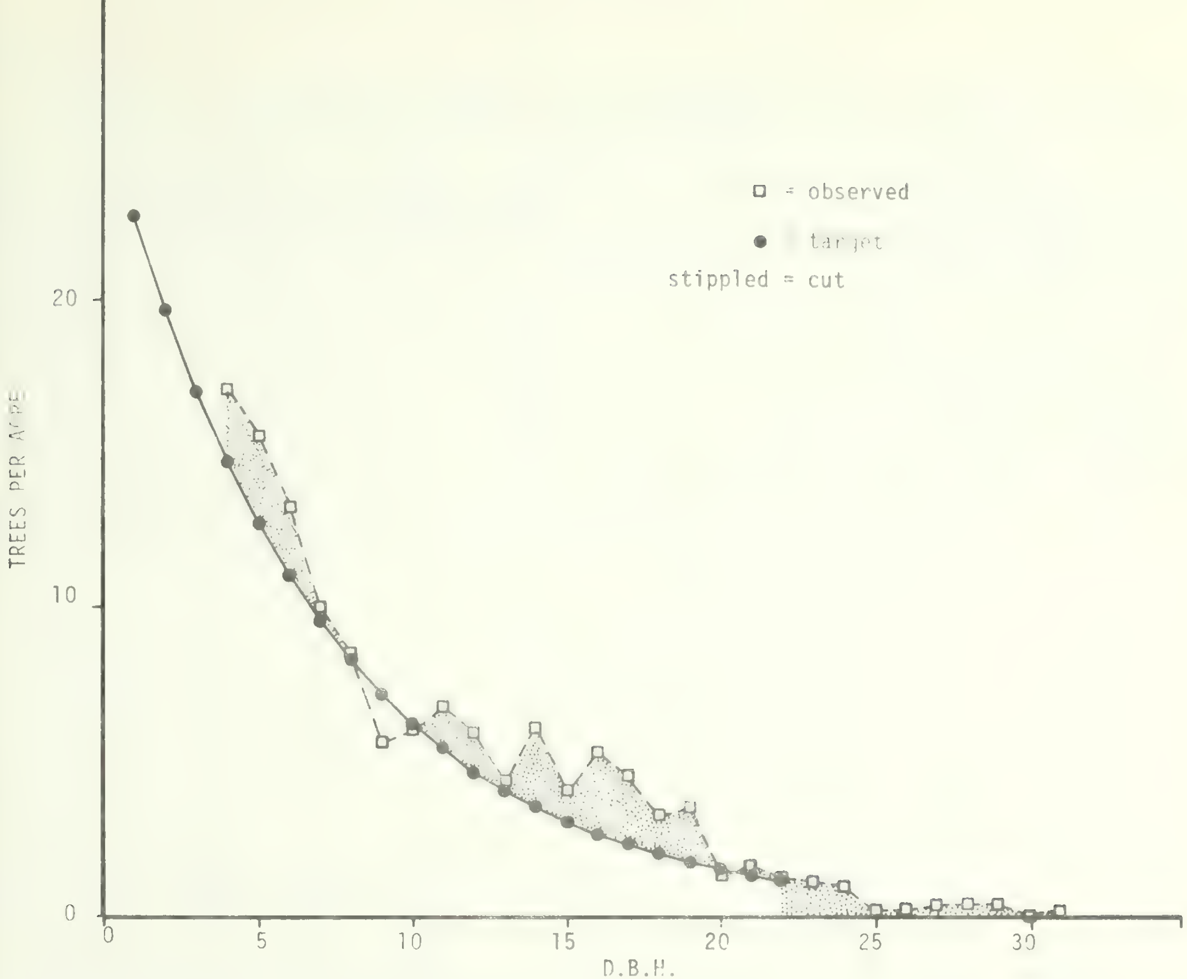

Figure 3.--Observed and after-cut target d.b.h. distributions for a selection stand of loblolly-shortleaf, SI=90 class.

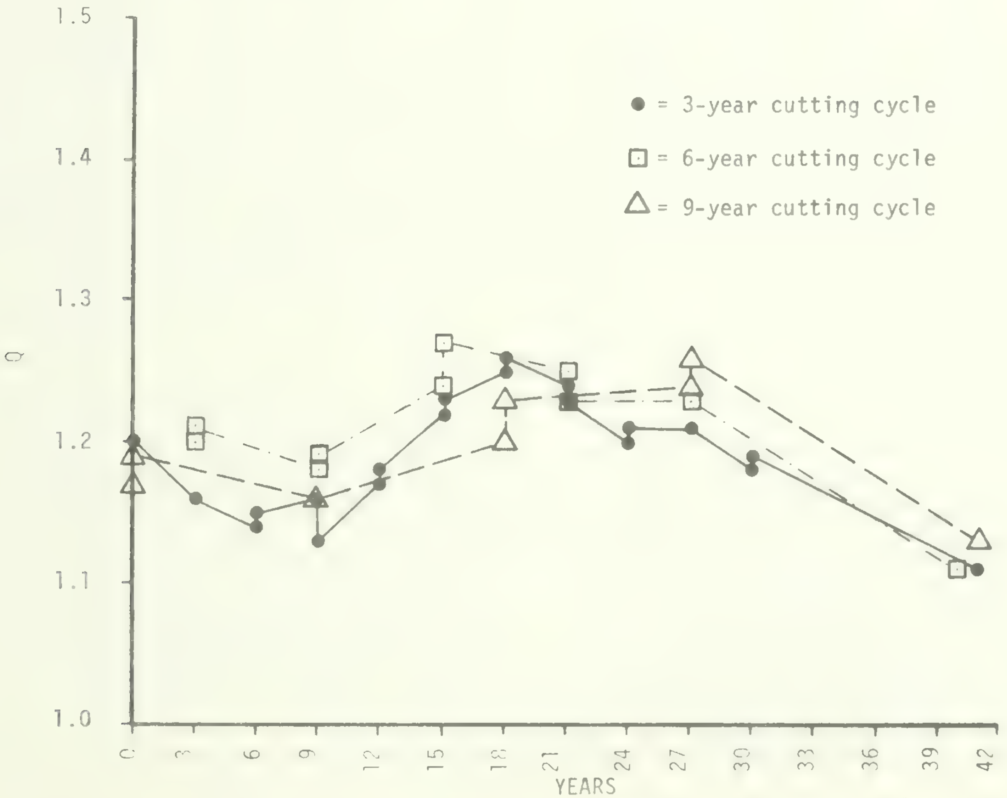

Figure 4.--Observed trends in fitted Q for selection stands of loblolly-shortleaf managed on three cutting cycles, SI=90 class.(3 reps. per c.c.).

Table 5.--Five-year BDQ projection of an optimum after-cut structure, SI=90 class.

```
  Type of Inventory :BEFORE-CUT PROJ.                TARGET STAND SUMMARY
  Compartment Number :SELECTION 2             SOUTHERN FOREST EXPERIMENT STATION
  Study :CUT METHODS                                RWU-1117, MONTICELLO
  Species :LOB-SHORT
  Date :APR.84


  Minimum DBH:   1
  Maximum DBH:   24
  Q Ratio : 1.155
  DBH Class Width : 1
  Exponent on DBH : 1
  Basal Area per Acre : 75
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

DBH      TPA      BA/A      MERCV     SAWCV     TOPCV     DOYLE    INT/4    SCRIB

                                   Per Acre

  1     26.01      .14       0.0       0.0       0.0         0        0        0
  2     22.52      .49       0.0       0.0       0.0         0        0        0
  3     19.50      .96       0.0       0.0       0.0         0        0        0
  4     16.88     1.47       8.6       0.0       0.0         0        0        0
  5     14.62     1.99      25.9       0.0       0.0         0        0        0
  6     12.65     2.48      43.2       0.0       0.0         0        0        0
  7     10.96     2.93      59.6       0.0       0.0         0        0        0
  8      9.49     3.31      74.8       0.0       0.0         0        0        0
  9      8.21     3.63      88.3       0.0       0.0         0        0        0
 10      7.11     3.88     100.0      47.8      52.2       200      368      190
 11      6.16     4.06     109.7      69.5      40.2       245      494      359
 12      5.33     4.19     117.3      84.0      33.4       299      577      469
 13      4.61     4.25     123.0      93.6      29.4       356      633      541
 14      4.00     4.27     126.8      99.9      26.9       411      670      588
 15      3.46     4.25     128.8     103.9      24.9       461      696      619
 16      3.00     4.18     129.2     106.2      23.1       504      713      640
 17      2.59     4.09     128.3     107.2      21.1       540      725      654
 18      2.25     3.97     126.1     107.1      18.9       567      731      662
 19      1.94     3.83     122.8     106.2      16.6       587      732      666
 20      1.68     3.67     118.7     104.5      14.1       599      728      666
 21      1.46     3.50     113.9     102.1      11.7       604      720      662
 22      1.26     3.33     108.5      99.1       9.4       603      707      654
 23      1.09     3.15     102.8      95.5       7.2       596      690      642
 24       .95     2.97      96.7      91.5       5.3       585      668      626

       187.72    75.00    2052.8    1418.2     334.3      7155     9850     8639
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CONCLUSION

Some progress has been made in research on regulation of uneven-aged loblolly-shortleaf pine forests, but by no means has the final answer arrived. We look at our prediction and projection systems for selection stand regulation as approximations. We can regard the "volume-g.d.l." technique as stage 1, our stand-level basal area and volume predictors and projectors as stage 2, and adaptation of the BDQ system will probably be stage 3, and stage 4 will probably be similar to stage 3 except that non-constant Q or more flexible distribution functions (i.e., truncated Weibull) will be employed, if necessary. These may be required so that we can more closely characterize and predict for those residual d.b.h. distributio that do not closely approach an exponential. We may find that d.b.h. distributions other than the simple exponential are more efficient for certain growth and production objectives. But, whatever d.b.h. distribution shape is chosen, it must be sustainable, within limits, over time; which mean that it must allow for adequate periodic regeneration and subsequent ingrowth.

Table 6.--Selection stands contributing data on objective regulation via BDQ technique.

Name	Species	SI[1] (ft.)	BA (ft.²)	DMAX (in.)	Q	Reps. (no.)	Approx. Rep. Size (ac.)
Ouachita	short.	60	60	18	1.2	3	10
Ark-907	lob.-short.	80	60	20	1.2	3	10
U.A.M.	lob.-short.	80	50	22	1.1	2	10
U.A.M.	lob.-short.	80	50	22	1.3	2	10
LMS,	lob.-short.	70	60	20	1.2	1	10
PSSF	lob.-short.	70	50	15	1.2	1	10
	lob.-short.	70	40	10	1.2	1	10
LMS,	lob.-short.	90	60	22	1.2	1	10
CEF	lob.-short.	90	50	16	1.2	1	10
	lob.-short.	90	40	10	1.2	1	10
E-A Conv., CEF	lob.-short.	90	60	16	1.2	2	5
BA-Burn,	lob.-short.	90	100	18	1.2	12	2
CEF	lob.-short.	90	80	18	1.2	12	2
	lob.-short.	90	60	18	1.2	12	2
	lob.-short.	90	40	18	1.2	12	2
						66	

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[1] site index at age 50, loblolly except for Ouachita shortleaf stands

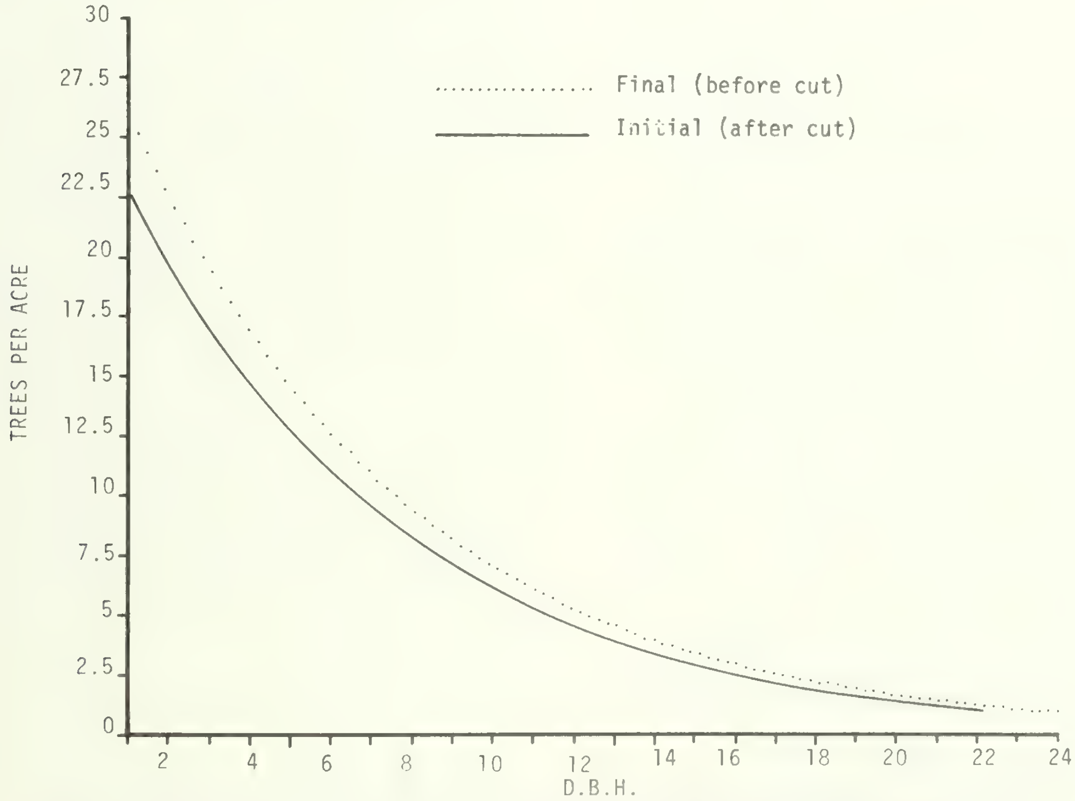

Figure 5.--BDQ d.b.h. distributions approximating optimum structures for loblolly-shortleaf selection stands using a 5-year cutting cycle, SI=90 class.

LITERATURE CITED

Alexander, R. R., and C. B. Edminster.
1977a. Uneven-aged management of old growth spruce-fir forests: cutting methods and stand structure goals for the initial entry. USDA For. Serv. Res. Paper RM-166, 12 p. Rocky Mountain For. and Range Exp. Stn., Fort Collins, Colorado.

Alexander, R. R., and C. B. Edminster.
1977b. Regulation and control of cut under uneven-aged management. USDA For. Serv. Res. Paper RM-182, 7 p. Rocky Mountain For. and Range Exp. Stn., Fort Collins, Colorado.

Brender, E. V.
1973. Silviculture of loblolly pine in the Georgia Piedmont. Georgia Forest Research Council Report No. 33, 74 p.

Davis, K. P.
1966. Forest management: regulation and valuation. Second edition. McGraw-Hill Book Company, New York, 519 p.

Hann, D. W. and B. B. Bare.
1979. Uneven-aged forest management: state of the art (or science?). USDA For. Serv. Tech. Rpt. Int-50, 18 p. Intermountain For. and Range Exp. Stn., Ogden, Utah.

Leak, W. B.
1963. Calculation of "q" by the least squares method. Jour. Forestry 61:227-228.

Leak, W. B.
1964. An expression of diameter distribution for unbalanced, uneven-aged stands and forests. For. Sci. 10:39-50.

Leak, W. B.
1965. The J-shaped probability distribution. For. Sci. 11:405-409.

Marquis, D. A.
1978. Application of uneven-aged silviculture and management on public and private lands. In: Uneven-aged silviculture and management in the United States. Timber Management Research, Forest Service, U.S. Dept. Agric., Washington, D.C., pp. 25-61.

Meyer, H. A.
1952. Structure, growth, and drain in balanced uneven-aged forests. Jour. Forestry 50:85-92.

Meyer, H. A., and D. D. Stephenson.
1943. The structure and growth of virgin beech-birch-maple-hemlock forests in northern Pennsylvania. Jour. of Agric. Res. 67:465-484.

Moser, J. W., Jr., and O. F. Hall.
1969. Deriving growth and yield functions for uneven-aged forest stands. For. Sci.15:183-188.

Murphy, P. A., and R. M. Farrar.
1980. Interim models for basal area and volume projection in uneven-aged loblolly-shortleaf pine stands. (In process)

Pearson, G. A.
1950. Management of ponderosa pine in the Southwest. USDA Monograph 6.

Reynolds, R. R.
1959. Eighteen years of selection timber management on the Crossett Experimental Forest. U.S. Dept. Agr. Tech. Bull. 1206, 68 pp., illus.

Reynolds, R. R.
1969. Twenty-nine years of selection timber management on the Crossett Experimental Forest. USDA For. Serv. Res. Paper SO-40. South. For. Exp. Stn., New Orleans, Louisiana, 19 pp.

Smith, D. M.
1962. The practice of silviculture. 7th edition. John Wiley & Sons, Inc., New York. vii + 578 p.

Trimble, G. R.,Jr., J.J. Mendel, and R.A. Kennell.
1974. A procedure for selection marking in hardwoods combining silvicultural considerations with economic guidelines. USDA For. Serv. Res. Paper NE-292, 13 pp. Northeast. For. Exp. Stn., Upper Darby, Pennsylvania.

Trimble, G. R.,Jr., and H.C. Smith.
1976. Stand structure and stocking control in Appalachian mixed hardwoods. USDA For. Serv. Res. Paper NE-340, 10 p. Northeast. For. Exp. Stn., Upper Darby, Pennsylvania.

U.S. Forest Service.
1978. Uneven-aged silviculture and management in the United States. Timber Management Research, Forest Service, U.S. Dept. Agric., Washington, D.C. 234 p.

GROWTH AND YIELD OF UNEVEN-AGED LOBLOLLY-SHORTLEAF PINE STANDS--A PROGRESS REPORT [1]

Paul A. Murphy [2]

Abstract.--Although uneven-aged growth and yield has been a neglected topic, some potentially useful approaches have been developed. Following is a synopsis of research-in-progress at Monticello/Crossett in applying these approaches and developing others.

INTRODUCTION

Much less information is available on the rowth and yield of uneven-aged stands than on hat of even-aged ones. Most forest management rganizations have chosen even-aged management or several reasons; for example, silvicultural asks can be administered efficiently, there is lready a large investment in tree improvement rograms, fire can be used as a silvicultural ool, and even-aged management usually needs less echnical expertise.

But interest in uneven-aged management as a ractical alternative has recently revived, articularly for private nonindustrial ownerships n the loblolly-shortleaf pines of the South. ortunately, research done elsewhere on uneven-ged growth and yield is a reservoir of experince and expertise. Some of this information has ecently been summarized (U.S. Forest Service 978, Hann and Bare 1979).

STATUS OF PRESENT KNOWLEDGE

Structural Description

Stand structure is important in management of uneven-aged stands. Stand structure can be defined as the number and distribution of trees per unit area by species, age, size, spacing, or other attributes. Here it is the distribution of trees by dbh classes. The French forester de Liocourt observed that the number of trees in successive dbh classes usually forms a smooth geometric progression (Meyer and Stevenson 1943, Meyer 1952), which can be represented graphically by a reverse J-shaped curve. The ratio of the number of trees in a given dbh class to the number in the adjacent higher class was usually constant. This ratio is called "Q". Meyer and Stevenson (1943) graphically fitted the logarithmic form of the reverse-J or exponential function to several virgin beech-birch-maple-hemlock forests in Pennsylvania and found that these stands usually followed a constant Q. later attempts at describing uneven-aged stand structure have focused on using some variant of the Q concept.

Leak (1963, 1964) showed how Q can be calculated by least squares and developed a technique for describing stand structure where Q values vary by dbh classes. He later (1965) emphasized that the exponential (sometimes called negative exponential) probability density function pdf could be used to describe uneven-aged stand dbh distributions and that the parameter of the distribution was functionally related to Q. Moser (1976) showed how a dbh distribution can be specified for a given exponential function, maximum tree size, and density--with density stated as basal area, tree-area ratio, or crown competition factor. To date, no one has tested the exponential pdf by empirically fitting it to stand dbh frequency data and comparing it with actual stand tables.

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Bailey and Dell (1973) fitted the Weibull pdf to uneven-aged stand data as an example and recognized that the exponential is a special form of the Weibull. In their example, the Weibull shape-parameter was fixed at 1 so they were fitting an exponential to the uneven-aged stand data rather than allowing the full Weibull to be estimated. Hyink and Moser (1979) fitted the three-parameter Weibull to uneven-aged hardwood dbh distribution data and modeled the change in the Weibull scale and shape-parameters over time. Stiff (1979) used the left-truncated two-parameter Weibull to represent dbh distributions of mixed-species Appalachian hardwoods.

In the past the exponential function has been used for providing a guide to desirable stand structure in uneven-aged stands. It is simple in concept and easy to apply. But it may not be possible to keep stands regulated to a Q structure, and a Q distribution may not be best for maximum growth. These problems are hypothetical and need to be proved or disproved by studies. The exponential has much precedence and attraction and is the logical candidate to test first.

Stand-Level Models

Some progress has been made in predicting growth and yield for uneven-aged stands. Moser and Hall (1969) formulated a growth and yield model for stand volume and stand basal area based on the principle that yield should be the integral form of the growth function. This idea had been used by Buckman (1962) and Clutter (1963) to develop equations for even-aged pine stands. The only variables they used were volume and basal area. Hyink and Moser (1979) developed a yield model based on predicted changes in the Weibull function fitted to dbh frequency data.

Moser later (1972) derived a system of first-order, ordinary differential equations for describing the components of net growth by basal area and number of trees. This system was later expanded (Moser 1974) to include different size classes.

Leary (1970) described how to predict survivor growth by size classes by using nonlinear ordinary differential equations for northern hardwood stands. Solution of these equations was based on the boundary values rather than least squares.

Ek (1974) formulated a series of nonlinear equations that described ingrowth, mortality, and survivor growth by dbh classes. Ingrowth was the number of trees growing into the smallest dbh class. The equations describing mortality and upgrowth were used for all size classes; there were no separate equations for each dbh class.

Stand table projection is a technique long used to make short-term forecasts of forest stands, both even- and uneven-aged. Wahlenberg (1941) is perhaps the best example of stand table projection techniques. A recent variant of stand table projection is the Markov chain approach: as in Peden, Williams, and Frayer (1973) and Bruner and Moser (1974).

Tree Level Models

The growth and yield models described so far have used either stand variables or variables that are aggregated values, such as number of trees by dbh class. Individual tree simulation is another approach to uneven-aged growth and yield modeling, in which the change in variables associated with individual trees is projected over time. Models of this type fall into two main groups--distance-independent and distance-dependent. The distance-dependent models use some measure of competition from neighboring trees. This measure is related to the distance between the simulated tree and the competitor tree. In distance-independent models, stand level attributes are used to modify the growth of the simulated tree. In both cases, attributes of the trees themselves are also used to model individual tree growth. The summation of the individual tree growth is stand growth. Most of these models have been developed for pure even-aged stands or plantations. There have been fewer attempts with mixed, uneven-aged stands.

Ek and Monserud (1974) developed a computer model called FOREST to simulate the growth and reproduction of plots in mixed species, even- or uneven-aged forest stands. The model incorporated tree size and inter-tree distances. Botkin, et al. (1972) developed a mixed species individual tree computer simulation model, in which the effect of other plot trees was defined in a variable that was the sum of the leaf areas of all the larger trees on the plot. Stage (1973) developed what was called a "prognosis model for stand development." It is a distance-independent tree growth simulator.

The advantages of stand-level versus individual tree models have been debated in recent years, and the general consensus seems to be that neither has better predictive power. The single-tree models provide a wealth of information, since they may be aggregated from the individual tree, but the cost of simulation with this type of model can be expensive. Costs, however, must be constantly re-evaluated because the rapid development of minicomputers is continually bringing down the cost of processing. The stand-level models offer the advantages of simplicity and low-cost simulation. Simplicity is not necessarily best, but it enables the observer to understand how the componants are working in relation to each other. The complexity of individual tree models can defy comprehension, sometimes even of the creator. Often choice of model may be dictated by the nature and form of the data.

For the initial investigation, Crossett Experimental Forest historical data going back to the late 1930's were available. The form of this information requires stand-level models, if these data are to be used. Also, it was felt that concentrating efforts in this direction will ultimately help in the development of single-tree models that may be needed in the future.

RESEARCH-IN-PROGRESS

This research program can be divided into three general areas: (1) prerequisite studies, (2) characterization of extant stand conditions, and (3) projection of the changes in these conditions over time with and without treatment.

Prerequisite Studies

Two studies were used in the area of preliminary research--investigations that are necessary for providing information needed as a basis for each research. The first study is the development of comprehensive tree volume and taper functions for naturally regenerated loblolly and shortleaf pines. Stem measurements of some 500 loblolly and shortleaf trees have been collected to date, and should total total about 600 when field measurements are completed. The results will enable researchers to calculate tree volumes for different merchantability standards and develop multiple-product yield estimates for trees and stands.

A study on how size of the research plot affects variability of selected stand variables was completed. The variables--basal area, number of trees, arithmetic mean diameter, quadratic mean diameter, sum of diameters, minimum diameter, and maximum diameter--were measured on plots varying by ¼ acre increments, from ¼ to 2 acres at 30 locations. Most coefficients of variation for these variables stabilized in the ½- to 1-acre range. These results will be used when the field studies are started.

Stand Characterization

The exponential or Q distribution has been used the most to describe uneven-aged stand structure and is the logical candidate for testing first. No one to date has rigorously tested whether the pdf form of the exponential is adequate in describing uneven-aged dbh distributions. Some 588 before-cut and 381 after-cut stand tables of uneven-aged loblolly-shortleaf pine (3.6 inches dbh and greater) managed under volume regulation were fitted to the left truncated and doubly truncated exponential pdf's. The doubly truncated assumes both a minimum and maximum dbh. The Kolmogorov-Smirnov one-sample test at the 5-percent level was used. Stands for these samples ran from 2.5 to 40 acres and can be considered as populations with known parameters. Rejection rates were 88 percent for before-cut and 89 percent for after-cut distributions fitted to the singly truncated form. The rejection rates for the doubly truncated ran 72 and 77 percent. Most rejections were due to deviations in the 4- to 9-inch dbh classes. The K-S test is rigorous because some stand tables exceeded 4000 trees. The slightly better performance of the doubly truncated exponential indicates that, perhaps, truncated forms should be looked at when other distributions are considered.

The stands used in this study were managed by the volume control method of stand regulation in which no particular emphasis is placed on maintaining or working towards a specified structure. The outcome could have been different if the stand had been managed to attain a particular dbh distribution. The exponential distribution may be useful for stands managed this way.

Projection of Stand Attributes

This last general area of research offers the greatest opportunity to pick and choose techniques and models of others. Because of the data limitations and the simplicity of the models, Moser and Hall's (1969) stand volume and basal area growth models were chosen for the first attempt. The only independent variables used are stand basal area and elapsed time. The basal area growth model is the generalized form of von Bertalanffy's growth-rate equation

$$dB/dt = nB^{m} - kB,$$

where:

dB/dt = periodic annual basal area growth (square feet per acre),

B = average basal area of pine 3.6 inches dbh and greater during the period, and n, m, and k are parameters.

The integral form is

$$B_t = \left[n/k - \left(n/k - B_0^{\,(1-m)} \right) e^{-(1-m)kt} \right]^{1/(1-m)}.$$

Stand volume is represented by the equation

$$V = b_0 B^{b_1},$$

where:

V = stand volume (cubic feet per acre, inside bark, of pines 3.6 inches dbh and greater from variable stump to a 3.5-inch top, inside bark);

B = basal area (square feet per acre); and

b_0, b_1 = parameters to be estimated.

Fitting the basal area growth equation resulted in

$$dB/dt = -.42457B^{1.0595} + .59116B,$$

and fitting the stand volume equation by nonlinear least squares yielded

$$V = 25.192B^{1.0209}.$$

The basal area growth equation coefficients are of the same relative magnitude and sign as Moser and Hall's (1969). The integral form of the basal area equation can be used to predict future stand basal area given initial basal area and elapsed time. Given present basal area and predicted future basal area, present and projected stand volumes can be calculated with the stand volume equation for the 90-ft site-index (loblolly, base age 50).

Most of the data had a range of 30-80 ft^2 in basal area. Basal area growth flattens perceptibly beginning at 60 ft^2 of basal area (fig. 1). The relationship of volume growth to basal area follows the same pattern as basal area growth (fig. 2).

These equations have enabled us to derive rough rules for growth and stand volume: (1) basal area growth of uneven-aged loblolly-shortleaf pine stands on site index 90 for loblolly will average about 3 ft^2 per acre per year, (2) annual volume growth is about 80 ft^3, and (3) these stands average about 27 ft^3 for every square foot of basal area. An average volume growth of 80 ft^3 agrees closely with the widely quoted average of 1 cord per acre per year for southern pines.

These two equations are the first effort in growth and yield, and research effort will be concentrated in this area. Work is progressing on development of a sawtimber volume yield model using these same data. Sawtimber volumes will be reported in board feet and cubic feet. This second development will still only be applicable to average sites and be based on local tree-volume functions.

Following completion of the sawtimber model, future models will be made more general by including other stand variables such as site quality. No measure of site quality has achieved the acceptance that site index has for even-aged forests. An adequate measure of site quality eventually must be found for uneven-aged loblolly-shortleaf pine stands. Since site index is such a widely used variable, an effort will be made to find out whether it might be used in somewhat altered form to estimate site quality in uneven-aged stands. A study is currently underway to test methods of soil-site evaluation for determining site index.

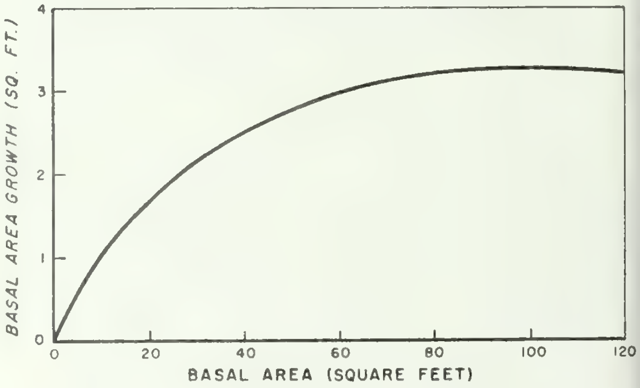

Figure 1.--Relationship of basal area growth to stand basal area for uneven-aged loblolly-shortleaf pine in south Arkansas

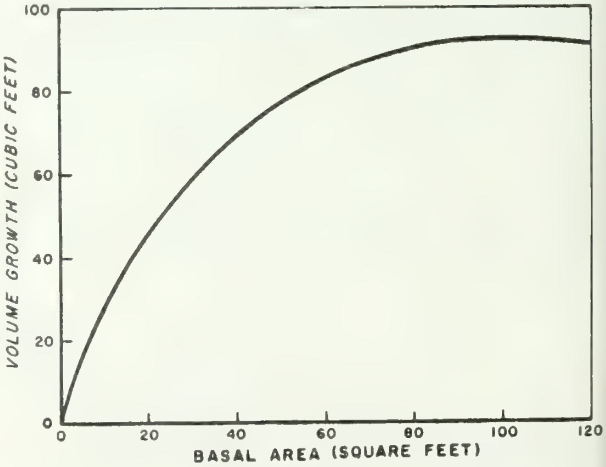

Figure 2.--Relationship of stand volume growth to stand basal area for uneven-aged loblolly-shortleaf pine in south Arkansas

Studies are continuing on stand structure. The next step in this area will be investigating other density functions like the Weibull. The truncated forms of distributions are particularly interesting, since stands are commonly regulated to a minimum merchantable dbh and maximum tree size. Limited experience with the exponential suggests that some gain in precision may result when the truncated forms are used. The exponential has not been discarded, because it may be useful for certain applications. Its efficacy for describing the diameter distributions of stands managed to a particular density, maximum dbh, and Q will be tested once data become available.

CONCLUSION

Efforts have been aided greatly by two factors. A broad charter has enabled researchers to look at the whole area of uneven-aged growth and yield for the loblolly-shortleaf pine type and to design a comprehensive, well integrated approach to problem solution. In the past, most uneven-aged work has been conducted in mixed species hardwoods, and the problem of species interaction has greatly complicated the problem. The task of modeling is greatly simplified by grouping loblolly and shortleaf pines together and initially ignoring the effects of hardwoods, which are usually burned or treated with herbicide periodically under pine management anyway. Benefit from these simplifications were sought, and the results so far have been encouraging.

LITERATURE CITED

Bailey, R. L., and T. R. Dell.
1973. Quantifying diameter distributions with the Weibull function. For. Sci. 19:97-104.

Botkin, D. B., J. F. Janak, and J. R. Wallis.
1972. Some ecological consequences of a computer model of forest growth. J. Ecol. 60:849-872.

Bruner, H. D., and J. W. Moser, Jr.
1974. A Markov chain approach to the prediction of diameter distributions in uneven-aged forest stands. Can. J. For. Res.3:409-417.

Buckman, R. E.
1962. Growth and yield of red pine in Minnesota. U.S. Dept. Agric. Tech. Bull. 1272, 50 p.

Clutter, J. L.
1963. Compatible growth and yield models for loblolly pine. For. Sci. 9:354-371.

Ek, A. R.
1974. Nonlinear models for stand table projection in northern hardwood stands. Can. J. For. Res. 4:23-27.

Ek, A. R., and R. A. Monserud.
1974. Forest: a computer model for simulating the growth and reproduction of mixed forest stands. Research Report A2635, College of Agric. and Life Sciences, Univ. Wisconsin, Madison, 14 p.

Hann, D. W., and B. B. Bare.
1979. Uneven-aged forest management: state of the art (or science?). U.S. Dept. Agric. For. Serv. Gen. Tech. Rep. INT-50. 18 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Hyink, D. M., and J. W. Moser, Jr.
1979. Applications of diameter distributions for yield projection in uneven-aged forests. In Forest Resource Inventories, p. 906-916, Vol. II, Colorado State University, Ft. Collins.

Leak, W. B.
1963. Calculation of "q" by the least squares method. J. For. 61:227-228.

Leak, W. B.
1964. An expression of diameter distribution for unbalanced, uneven-aged stands and forests. For. Sci. 10:39-50.

Leak, W. B.
1965. The J-shaped probability distribution. For. Sci. 11:405-409.

Leary, R. A.
1970. System identification principles in studies of forest dynamics. U.S. Dept. Agric. For. Serv. Res. Pap. NC-45, 38 p. North Cent. For. Exp. Stn., St. Paul, Minn.

Meyer, H. A.
1952. Structure, growth, and drain in balanced uneven-aged forests. J. For. 50:85-92.

Meyer, H. A., and D. D. Stephenson.
1943. The structure and growth of virgin beech-birch-maple-hemlock forests in northern Pennsylvania. J. Agric. Res. 67:465-484.

Moser, J. W., Jr.
1972. Dynamics of an uneven-aged forest stand. For. Sci. 18:184-191.

Moser, J. W., Jr.
1974. A system of equations for the components of forest growth. In: Fries, J. (ed.), Growth models for tree and stand simulation. Royal Coll. For., Stockholm, Res. Notes No. 30, p. 260-287.

Moser, J. W., Jr.
1976. Specification of density for the inverse J-shaped diameter distribution. For. Sci. 22:177-180.

Moser, J. W., Jr., and O. F. Hall.
1969. Deriving growth and yield functions for uneven-aged forest stands. For. Sci. 15:183-188.

Peden, J. M., J. S. Williams, and W. E. Frayer.
1973. A Markov model for stand projection. For. Sci. 19:303-314.

Reynolds, R. R.
1959. Eighteen years of selection timber management on the Crossett Experimental Forest. U.S. Dep. Agric. Tech. Bull. 1206, 68 p.

Reynolds, R. R.
1969. Twenty-nine years of selection timber management on the Crossett Experimental Forest. U.S. Dep. Agric. For. Serv. Res. Pap. SO-40, 19 p. South. For. Exp. Stn., New Orleans, La.

Stage, A. R.
1973. Prognosis model for stand development. USDA For. Serv. Res. Pap. INT-137, 32 p. Interm. For. and Range Exp. Stn., Ogden, Utah.

Stiff, C. T.
1979. Modeling the growth dynamics of natural mixed-species Appalachian hardwood stands. Unpublished Ph.D. Dissertation, Virginia Polytechnic Institute and State University, Blacksburg, 206 p.

U.S. Forest Service.
1978. Uneven-aged silviculture and management in the United States. Timber Management Research, U.S. Dep. Agric., For. Serv., Washington, D.C., 234 p.

Wahlenberg, W. G.
1941. Methods of forecasting timber growth in irregular stands. U.S. Dept. Agric. Tech. Bull. 796, 56 p.

IMPACT OF PINE REGENERATION ON SOIL MICROORGANISMS[1]

Shih-Chang Hu, J. M. Larkin and S. L. Edwards[2]

Abstract.--Approximately 160 acres of mature loblolly pine were regenerated by the methods of clearcutting, seed-tree, shelterwood, and selection in southeastern Louisiana. Soil samples for microbiological examination were collected before and after the regeneration cuttings. Results showed that regeneration cuttings influenced the population of soil microorganisms.

INTRODUCTION

Soil fertility and productivity have been correlated with the abundance of microorganisms and their activities. The number of microorganisms varies with environmental factors such as oxygen supply, moisture content, temperature, acidity, organic matter, and season of the year. The practices of regeneration cuttings change the forest environment and hence may influence the population and activities of the soil microorganisms.

Niemala and Sundman (1970) reported that clearcutting of spruce in northern forest soils had caused a significant relative increase in caseolytic and lipolytic, rhamnose negative organisms, which also had a low acid tolerance. Cutting also increased bacteria of the genera Nitrosomonas and Nitrobacter 18-fold and 34-fold respectively (Smith et al. 1968). The population of soil microorganisms varies from one kind of forest to another. Chase and Baker (1954) compared microbial activity in Ontario forest soils under pine, hemlock and maple. Their results supported other workers' conclusions (Lutz and Chandler 1952, Russell 1950) that fungi predominate in coniferous forests. The fungi outnumbered the bacteria and actinomycetes combined.

Few studies of the microorganisms and their activities in the forest soils in the South have been done. The purposes of this study were to determine the numbers and types of soil microorganisms under a mature loblolly pine forest and to determine what changes may occur following regeneration cuttings.

METHODS AND PROCEDURES

Sampling Site

A study to determine the effects of pine regeneration on soil microorganisms was established in 1975. Approximately 160 acres of mature loblolly pine were regenerated by the methods of clearcutting, seed-tree, shelterwood and selection at Idlewild Experiment Station in southeastern Louisiana.

Five treatments and two replications were used. An undisturbed site in the same forest was chosen as a control. The control site was designated as site 1, the selection area as site 2, the shelterwood area as site 3, the clearcut area as site 4, and the seed-tree area as site 5. All sampling areas were in the middle of a square area approximately 40 m to a side within a 20-acre plot.

Sampling Procedure

Soil samples were collected from an area of approximately 10 cm^2 and from the top 3 cm as described by Larkin and Dunigan (1973), after brushing away the accumulated litter. Samples were placed in sterile whirl-pak plastic bags and immediately transported to the laboratory at ambient temperature, where each was homogenized by mixing and then analyzed.

An intensive microbiological examination was conducted with 4 precutting samplings obtained over a year to determine seasonal changes and to obtain baseline data. One sampling was done 3 weeks after cutting.

Laboratory Procedure

Soil samples were serially diluted and plated in triplicate to determine the populations of specific groups of microorganisms. For total aerobic bacterial populations peptonized milk agar (PMA) containing cycloheximide was used

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(Larkin 1972). Actinomycetes and fungi were enumerated on Actinomycete agar and Sabouroud Dextrose agar respectively. Cellulolytic and proteolytic organisms were enumerated by detecting zones of clearing around colonies on PMA agar overlaid with a thin layer of 20% cellulose or 50% casein respectively. An aliquot of the diluted sample was heated for 10 min at 80°C and plated on nutrient agar to count sporeformers. Incubation of all plates was at room temperature and counts were recorded at 7 days (proteolytic organisms), 14 days (total bacteria, sporeformers, actinomycetes and fungi) or 21 days (cellulolytic organisms).

Approximately 100 organisms were isolated from each soil sample from the PMA plates. They were characterized with a battery of 22 biochemical tests using the BBL Minitek system. In addition, each isolate was examined by standard techniques for its ability to hydrolyze gelatin and casein, and to produce catalase and cytochrome oxidase. The Gram reaction, cell and colonial morphologies were examined on 18-hr cultures grown on nutrient agar. All of the features which were analyzed are shown in Table 2.

Factor Analysis of Results

The characteristics of each isolate were encoded binomially for statistical evaluation. The correlations between each pair of n tests were calculated for all isolates, and the n x n correlation matrix was condensed by factor analysis to a J-dimensional factor space (Sundman, 1968). The factorization was carried out as a principal axis factor solution using maximum correlation of each variable as the estimate of communality.

Factors were extracted and subjected to between/within population analysis of variance to determine their discriminative powers. Factors which gave between/within ratios of $p \geq 0.05$ were excluded as non discriminative (Sundman 1970).

RESULTS AND DISCUSSION

The numbers of total aerobic bacteria, proteolytic organisms, fungi, sporeformers, actinomycetes, and cellulolytic organisms from each sampling date are listed in Table 1.

Total Aerobic Bacteria Count

The number of total aerobic bacteria fluctuated among sampling dates. Following the regeneration cutting, the count in the control site decreased about 10 fold from the previous count. A decrease in about the same amount was also found in other sites. Thus, the decrease in total count may be due to seasonal change rather than regeneration cuttings.

The numbers of total aerobic bacteria at all sites ranged from 10^6 to 10^7/g dry wt. of soil. Other workers (Rybalkina 1957, Stout 1961, Terehov and Enikeeva 1964, Berry 1967) have found that total aerobic bacteria in coniferous forests ranged from 10^5 to 10^6/g dry wt. The bacteria were most numerous in April and least numerous in July. Fungi were most numerous in July and least numerous in April. This pattern was also observed by Wright and Bollen (1961) whose studies of a douglas fir forest indicated that when bacteria were most abundant fungi were least numerous and vice versa.

Proteolytic Organisms

The proteolytic bacteria showed a relationship with the seasons. The counts were generally higher in the summer and fall than in the winter and spring. The populations of the proteolytic organisms increased after regeneration cuttings.

Fungi

The numbers of fungi fluctuated at the various sampling dates with no obvious relationship to seasons. The predominant genera seen were Penicillium spp., Aspergillus spp., Alternaria spp., and Rhizopus spp. In three of the four samples obtained before cutting, the bacteria outnumbered the fungi by levels of 2 to 10 fold. After cutting, the fungi outnumbered the bacteria by 2 to 3 fold. Thus, the cutting raised the fungal population. It rained for an extensive period of time before the last sample was collected and this could have contributed to the increased number of fungi. Warcup (1957) reported that fungi increase in numbers after heavy rainfall. Other workers (Chase and Baker 1954, Lutz and Chandler 1952, Russell 1950) have found that the fungi predominate in coniferous forests and that fungi usually outnumber bacteria and actinomycetes combined. Terehov and Enikeeva (1964), however, found that mean counts of bacteria outnumbered combined counts of fungi and actinomycetes by 3 fold.

Sporeformers

The counts of the total sporeforming bacteria fluctuated among the sampling dates, but they did not seem to correlate with specific seasons. However, in all samples obtained after cutting they were at their lowest levels. The decrease following the cutting cannot be attributed to the cutting because the control site also decreased to its lowest level.

Before cutting, the sporeformers accounted for approximately 15-30% of the total bacterial population. After cutting they accounted for 5-10% of the bacterial population. The level of sporeformers decreased more rapidly after cutting than did the bacterial population as a whole.

Table 1.--The counts of various classes of microorganisms at Idlewild Experiment Station (forest 1) at various times before and after cutting

Sample	February[1] 14, 1976	July 7, 1976	October 16, 1976	April 20, 1977	December 14, 1977
Total aerobic bacteria					
Control site	3450[2]	280	5860	4080	410
Site 2	5020	3840	2830	3810	400
Site 3	3200	4550	1110	6400	410
Site 4	1700	1230	2910	11500	2040
Site 5	3780	2550	12000	3020	570
Mean of 2-5	3425	3043	4712	6182	855
Proteolytic organisms					
Control	120	1380	2200	100	100
Site 2	870	12000	760	410	1880
Site 3	260	1460	360	100	420
Site 4	250	1340	4500	230	710
Site 5	530	6100	10700	230	1260
Mean of 2-5	420	5225	4080	242	1067
Fungi					
Control	1100	280	590	440	460
Site 2	520	11800	1000	400	2210
Site 3	650	1030	530	830	1260
Site 4	840	1690	1140	710	1670
Site 5	630	1760	880	260	1080
Mean of 2-5	660	4510	888	550	1555
Sporeformers					
Control	520	430	520	130	22
Site 2	880	410	340	490	32
Site 3	380	1840	890	290	18
Site 4	370	370	2300	2400	90
Site 5	420	2350	380	2000	71
Mean of 2-5	513	1160	978	1295	53
Actinomycetes					
Control	1360	30	3940	530	1800
Site 2	1680	4310	2790	1960	60
Site 3	500	480	470	3020	30
Site 4	820	400	1820	550	460
Site 5	950	1780	5760	1690	80
Mean of 2-5	988	1743	2710	1515	158
Cellulolytic organisms					
Control	2.9	2.2	2.7	2.4	2.5
Site 2	5.8	4.8	3.1	2.7	2.9
Site 3	3.5	3.4	2.9	3.1	2.8
Site 4	8.4	7.1	7.5	7.8	4.3
Site 5	3.3	2.9	2.9	1.4	3.1
Mean of 2-5	5.2	4.6	4.1	3.8	3.9

[1] February, July, October and April are precutting sampling dates; December is the sample taken three weeks after cutting.

[2] Counts x 10^4/gram dry weight.

Actinomycetes

The level of actinomycetes fluctuated in a way that could not be directly related to changing seasons. After cutting, the experimental sites contained only 3-5% of the actinomycetes that were found in the control sites. Regeneration cuttings decreased the population of the actinomycetes. In all cases before cutting the numbers of actinomycetes were equal to about 25-50%

Table 2.--Extract of principal axes matrix of Idlewild Experiment Station. First two estimates of loadings ≥ 0.30 are given. Plus signs are omitted.

Character	Factor I	II	III	IV	V
Cells spherical				-0.35	
Rods axis straight				0.39	
Rod w pointed ends					
Flexuous rods					
Endospores present		0.71			
Endospores spherical					
Endospores central to subterminal		0.66			0.31
Sporangium swollen		0.42			0.33
Capsule					
Gram + or variable					
Cells: singly					
pairs					
irregular clusters		-0.40			
chains		0.46			
packets					
palisades					
rosettes					
Colony pigmented			-0.31	0.62	0.55
Carotenoid pigments			-0.31	0.62	0.55
Fermentation of a pentose	0.38		0.68	0.31	
Fermentation of xylose	0.56				
Fermentation of arabinose	0.34		0.70	0.32	
Fermentation of rhamnose	0.42				
Fermentation of hexose	0.70		0.33		
Fermentation of fructose	0.66			0.37	
Fermentation of glucose	0.69				
Fermentation of salicin	0.60				
Fermentation of a disaccharide	0.70				
Fermentation of sucrose	0.65				
Fermentation of lactose	0.57				0.32
Fermentation of raffinose	0.47				
Fermentation of starch					
Arginine decarboxylase			-0.30		-0.35
Phenylalanine deaminase					
Malonate utilization					-0.34
Citrate utilization	0.31				-0.36
Acid from glucose aerobically	0.48				
Nitrate reduction	0.32				
H_2S production					
Indole production					
Urease production					
Casein digestion		0.46			
Gelatin hydrolysis		0.46			
Catalase production					
Cytochrome oxidase		0.32			
Mannitol utilization	0.48				
Gylcerol utilization	0.50				
Vogues-Proskauer					
Factor variances:	7.12	6.78	10.04	8.02	4.99
% of total :	19.20	18.30	27.20	21.70	13.50

of the total bacterial count. After cutting this population dropped to about 10-15% of the total bacterial population.

Actinomycetes numbered in the range from 10^6 to 10^7/g dry wt. of soil and were most numerous in October. Rybalkina (1957) found actinomycetes present at lower numbers and they were most numerous in October. Terekhov and Enikeeva (1964) reported forest soil populations in which the actinomycetes numbered 10^5/g dry wt.

Cellulolytic Organisms

The populations of cellulolytic organisms remained relatively constant at each site throughout the experimental period and were approximately 1-2% of the total bacterial population. After cutting, there was no significant change in the populations.

Factor Analysis

From an analysis of each of the bacterial isolates, five factors were extracted. The factors are shown in Table 2. Factor I was primarily a carbohydrate fermentation factor. Factor II was a Bacillus (sporeformer) factor. Factor III was a nonpigmented, arabinose and fructose fermenting group. Factor IV was dominated by carotenoid pigment containing rods of the Flavobacterium-Cytophaga group. Factor V also contained carotenoid-pigmented organisms but also included spores and is thus interpreted as a pigmented sporeformer group.

Although the relative input of the factors into the total microbial picture changed with the seasons, only factors II and V followed a discernible pattern. Factor V (pigmented sporeformers) had its maximum input during the summer and its minimum input during the winter. Factor II (Bacillus) showed the opposite response. This may be due to increased sunlight in the summer, as discussed below.

Two important features appeared as a result of the factor analysis. First, after harvesting the trees the importance of the nonpigmented sporeformers (II) and the carbohydrate fermenters (I) decreased while the two factors (IV and V) which contain the carotenoid pigmented groups increased in importance. This very likely is due to selective pressure on the microbial populations brought about by the increased amount of sunlight hitting the forest floor after harvest. Carotenoid pigments protect bacteria from photooxidation (Liaaen-Jensen 1965) and bacteria which produce them had a selective advantage when the forest floor suddenly received an increase in sunlight.

Second, before harvesting the trees in the experimental sites the factor analyses showed that the relative importance of each factor varied from site to site. This indicated that the sites themselves were not identical even though they were selected on the basis of their overall similarity in slope, overhead cover, etc. After harvesting, the inputs of the various factors from all experimental sites came closer together when compared with their spread at previous times. Thus, the vegetation cuttings converted four sites with dissimilar microbial populations into four very similar sites. This may be due to two factors. The removal of all or most of the trees would make the sites more alike by equilibrating their exposure to sunlight, wind, rainfall, etc., and secondly, the disruptive effects on the soil by the logging crews and equipment would tend to reduce the differences among the sites.

LITERATURE CITED

Chase, F. E. and G. Baker.
1954. A comparison of microbial activity in an Ontario Forest Soil under Pine, Hemlock and Maple Cover. Can. J. Microbiol. 1:45-54.

Larkin, John M.
1972. Peptonized Milk Agar as an Enumeration Medium for Soil Bacteria. Appl. Microbiol. 23(5):1031-1032.

Larkin, John M. and Edward Dunigan.
1973. Myxobacteria from Southwestern USA Soils. Soil Sci. Soc. Amer. Proc. 37:808-809.

Liaaen-Jensen, S.
1965. Bacterial carotenoids. XVIII. Acrylcarotenes from Phaeobium. Acta Chem. Scand. 19:1025-1030.

Lutz, H. J. and R. F. Chandler.
1952. Forest Soils. John Wiley and Sons, Inc. New York.

Niemala, Seppo and Veronica Sundman.
1976. Effects of clear cutting on the composition of bacterial populations of northern spruce forest soil. Can. J. Microbiol. 23:131-138.

Russell, E. W.
1950. Soil Conditions and Plant Growth. 8th ed. Longmans, Green and Company, Inc. London, New York, Toronto.

Rybalkina, A. V.
1957. Microflora of Soils in European USSR. Microflora of Tundra, Podzolic and Chernozem Soils. Moskva, Izdate's STVO. An. SSSR.

Smith, W., F. H. Bormann and G. E. Likens.
1968. Response of chemoautotrophic nitrifiers to forest cutting. Soil Science. 106(6):471-473.

Stout, J. D.
1961. A Bacterial Survey of Some New Zealand Forestlands, Grasslands and Peats. N. Z. Jl. Agric. Res. 4:1-30.

Sundman, Veronica.
1968. Characterization of Bacterial Populations by Means of Factor Profiles. Acta. Agric. Scand. 18:22-32.

Sundman, Veronica.
1970. Four Bacterial Populations Characterization and compared by a factor analytical method. Can. J. Microbio. 16:455-464.

Terekhov, O. S. and M. G. Enikeeva.
1964. Comparative Microbiological Characteristics of Some Forest Soils in the Forest Districts Serebryanoborsk and Poduskkinsk, the Moscow Region in Spornik: Statsionakye brigeotsenoficheskie moskva. Izdatel Stvo Nauka.

Warcup, L. H.
1957. Studies on the Occurrence and Activity of Fungi in a Wheat-field Soil. Trans. Brit. Mycol. Soc. 40:237-262.

Wright, E. and W. Bollen.
1961. Microflora of Douglas-Fir Forest Soil. Ecology. 42:825-828.

A COMPARISON OF CATION SAMPLING IN FOREST SOILS BY TENSION AND TENSION-FREE LYSIMETERS[1]

James H. Miller[2]

Abstract.--Field tests conducted in two soils with ceramic cup, ceramic plate, and tension-free lysimeters showed no concentration differences in collected cations (Ca, Mg, K, Na) between cups and plates, except for the hydrogen ion. Mean pH was 0.6 lower in cup collected samples for a sandy loam profile. Tension-free lysimeters of the design tested had persistent contamination from a glasswool component and yielded samples at a 60 cm depth from a clay loam profile and not from a loamy sand soil. Laboratory trails showed a marked response delay with plate lysimeters when sampling changing cation concentrations.

INTRODUCTION

Tension and tension-free lysimeters are being used more often to monitor natural processes in soil profiles and nutrient-loss impacts after cultural treatments. These devices permit solution sampling within and beneath undisturbed soil profiles. This cannot be done yet by other means. Tension lysimeters with porous ceramic cups have been used to monitor environmental contaminants (Parizek and Lane 1970, Nutter et al. 1978, Neary et al. 1979) and nutrient leaching processes (Vitousek et al. 1979, McColl 1978, Gosz and Dyck 1979). Tension plate techniques developed by Cole (1968) have clarified leaching mechanisms (McColl and Cole 1968) and nutrient losses following forest practices (Gessel and Cole 1965, Grier and Cole 1971). Jordon (1968) refined techniques using tension-free lysimeters and employed these to investigate nutrient transfers in tropical forest ecosystems (Kline and Jordon 1968; Stark and Jordon 1978). The investigative potential of such sampling devices is great, but the validity of cation sampling by the different lysimeters has not been fully explored.

The objective of this study was to compare tension-cup, tension-plate, and tension-free lysimeters for quantifying nutrient losses from forest lands after vegetation management treatments. Each device was tested in the laboratory for response variation while sampling known concentrations of cations. A field study tested differences in concentrations from devices placed in isolated profiles with vegetation uptake eliminated. Sampling bias with the ceramic cup has already been shown for phosphate (Hansen and Harris 1975) and ammonium (Wagner 1962) which were not studied further here.

MATERIALS AND METHODS

Ceramic cup and plate samplers used in this investigation are the commercial models manufactured by Soil Moisture Equipment Corp., Santa Barbara, California.[3] The ceramic cup has a 2-bar bubbling pressure (or air entry value) with an outside diameter of 49.5 mm, an exposed length of 61 mm and ceramic thickness of 2 to 3 mm. Specified lengths of polyvinyl chloride (PVC) pipe are cemented to the cup permitting greater sampling depth and differing ratios of sample volume to vacuum-reservoir. The 60 cm length of PVC was tested here.

Plates are constructed of 0.5 bar ceramic with variable diameters of 265 to 275 mm and a thickness of 9 mm. A rubber disk with outport is attached to one side of the ceramic plate by peripheral wire and cement with a screen interlayer to permit water flow. Connection between outport and a combination vacuum-sample bottle is by vacuum hose and copper tubing. Solutions collected with the plate must travel through 3 to 4 times more ceramic material than with the cup samplers, which have absorptive properties.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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[3] Use of trade, firm or corporation names in this publication is for the information and convenience of the reader. Such use is not an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

Ceramic cups are made from a non-vitreous porcelain which contains more or less equal proportions of kaolin, alumina (Al_2O_3), ball clay, and other feldspathic materials.[3] The Al_2O_3 is essentially pure and 30% of the kaolin and ball clay are composed of this compound. Plates are 90% Al_2O_3, 6% kaolin and 4% ball clay. Kaolin and ball clay in both lysimeters are over 50% by weight SiO_2 and have potential contaminants of iron, calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), and titanium in amounts less than 1.5% each. Initial treatments of ceramic samplers are used to reduce the leachable or exchangeable cation contaminants (Gover and Lamborn 1970, Wolff 1967). I washed all ceramic samplers first with distilled water (DW) to remove ceramic dust, then 300 ml of 1N HCl was drawn through each, and finally, 1.2 liters of DW was tensioned through each lysimeter. This volume of DW was required before cation contamination reached zero.

Tension-free lysimeters were constructed of a 285 mm diameter funnel made by cutting off the upper portion of a 20-liter plastic carboy at the shoulder and inverting it on the bottom as a base. A drilled hole in the carboy cap with an epoxied connector served as an outport permitting tubing to be attached to a sample bottle. Glasswool filled the funnel and facilitated water flow (Stark and Jordon 1978). Repeated acid treatment (2% HCl) and DW washes of laboratory-grade glasswool was unsuccessful in eliminating cation contaminants. Average contaminant concentrations in a 300 ml DW wash were Ca 0.9 mg/l, Mg 0.5, K 0.2, and Na 2.0. Polyester fiber was also substituted for the glasswool and yielded similar contaminant concentrations. Due to this problem, tension-free data will be presented separately in the laboratory and field results.

In the laboratory trails, 300 ml aliquots of a premixed solution of four cations were sequentially drawn (0.4 bar tension) or passed (tension-free) through the samplers and analyzed using standard atomic absorption techniques. The solution concentrations were Ca 0.85 mg/l, Mg 0.45, K 0.23 and Na 3.10. Finally a 300 ml DW was then drawn or passed through each and analyzed. This procedure was repeated on three devices of each type to test the responsive capabilities of the samplers.

In field comparisons, three lysimeters of each type were installed in a randomized complete block design with three blocks in a loamy sand an three in a clay loam soil. The two installations are about 150 m apart and both are located in natural clearings under 53-year-old plantations of loblolly (Pinus taeda) and shortleaf pine (P. echinata). An access trench 1.5 m wide, 3 m long, and 1.5 m deep in the clearing centers was provided with a wooden shelter, with open sides for profile access. A sloping roof drained away from the installations. Tension plates and tension-free samplere were installed laterally in the trench walls. Cups were installed by auger holes using a 200-mesh silica sand interfacing material at the bottom of the hole. Lysimeters were emplaced at a 60 cm depth on the loam sand site and at 45 cm on the clay loam site, below lateral rooting of the pines and equidistant from the access trench. A 30 cm wide and 1.5 m deep root exclusion trench surrounded the installation at a distance of 1.5 m from the access trench. Polythene sheeting was backfilled to the inside walls of the trenches to prevent root encroachment. All vegetation within each installation was carefully cleared and kept clear for the duration of the study. Thus plant uptake was eliminated as a variable.

A vacuum of 0.3 bars was maintained on tension devices over a collection period only during times of adequate soil moisture. At low soil moisture, cups maintained tensions more consistently than the plates, which required reevacuation periodically. Although cups maintained vacuum at lower soil moisture than plates, very little sample was collected during these periods. Tension-free lysimeters collected samples only after intense storm events.

Soil solution was collected 3 days after storm events or biweekly during extended rainy periods. Analyses included specific conductance Ca, Mg, K, Na, and pH. Specific conductance was measured with a conductivity meter with samples placed in a 25°C bath. Cations were determined by atomic absorption spectrophotometry. The pH was measured potentimetrically.

RESULTS AND DISCUSSION

It is commonly thought that ceramic samplers reach equilibrium with the soil solution after installation. Thus, the process of adsorption, diffusion, and screening which biased phosphate sampling (Hansen and Harris 1975) merely delay the actual changes in soil solution concentration when monitoring a profile. This detection delay can readily be seen in the laboratory results with the plate samplers (Fig. 1). With Ca, 1.5 liters of a 0.85 mg/l solution were drawn throug the plates before the premixed sample concentrations were approached. Other cations reached equilibrium within 600 ml.

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[3] Personal communications with Mr. P. E. Skaling, Soil Moisture Equipment Corp.

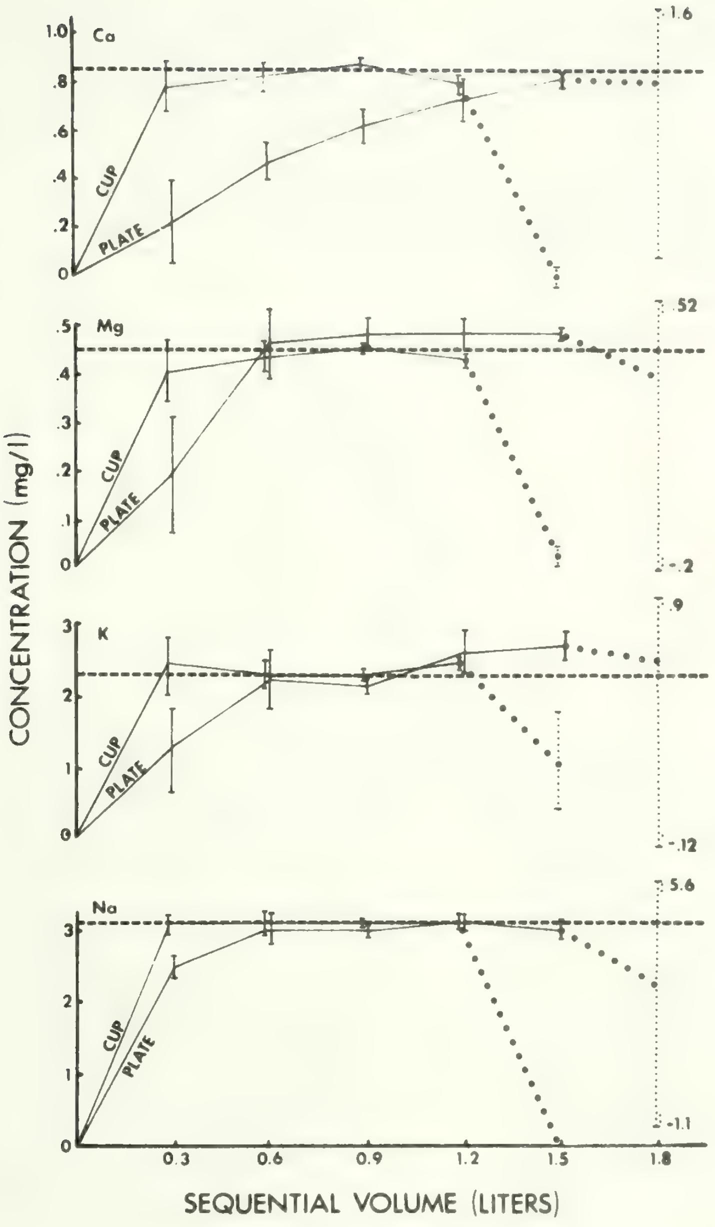

Figure 1. Mean concentrations of samples drawn from a known solution (concentrations indicated by horizontal dashed lines) and the sample standard deviations (vertical lines). The dotted lines indicate a final distilled water wash (0.3 liters) and the subsequent wash concentration.

Concentrations higher than the test solutions were found in samples for Mg and K. This phenomenon and the variable concentrations in the DW, evident by the large standard deviations, must result from desorption of bound ions. The large standard deviation also shows this desorption response to vary greatly from plate to plate. The plate with the slowest concentration response had the slowest average flow rate.

No percolating water reached the tension-free sample containers at the sandy site.

Using sample concentrations from the 12 storm as observations, a two-factor analysis of variance tested differences (1%) between soils and between cup and plate lysimeters. An additional analysis of variance and Duncan's multilple range tests wer performed on the three lysimeter types using the tension-free collections in the clay loam soil.

Table 1. Mean cation concentration in solution washes of known concentration and a final wash of DW through tension-free lysimeters.

Solution	Ca	Mg	K	Na
	mg/l			
Premixed Concentration	0.85	0.45	0.23	3.1
1	7.52	1.05	.72	15.8
2	3.44	1.83	.67	15.1
3	2.21	1.09	.38	7.4
4	1.60	.80	.26	4.8
5	1.42	.71	.23	4.2
DW wash	2.82	1.32	.73	8.1

Cup lysimeters showed a more rapid response to drastic concentration changes. Although deviations from test resolution concentrations of ± 1% are apparent, the accuracy of analysis approximates ± 1% at these concentrations. Potassium desorption or leaching in the DW wash of cups points to a source of sampling bias with decreasing concentrations.

Persistent contamination was in the solution washes and DW washes passed through the tension-free devices (Table 1). Sodium was most concentrated. These devices had been previously washed with over 20 liters of DW in an attempt to eliminate the glasswool contaminants. The premixed concentration of K was finally reached after 1.5 liters, but absorbed or bound ions of all cations were leached in the DW wash.

Twelve storm periods were sampled at the field sites between July and November 1979. The longest storm was two weeks and the shortest 3 days. All devices had been previously installed and samples collected for at least 2 months before the July sampling commenced. This waiting period allowed for ample equilibration time. If equilibration of the ceramics does take place, then solution concentrations collected from both devices in the uniformized soil profiles should be the same. Collection from tension-free lysimeters were only made at the clay site during the sampling period.

Mean values for the 12 collections presented in Table 2, show no significant differences (1% level) between cups and plates for specific conductance, and Ca, Mg, K, and Na concentrations The two samplers in loamy sand and clay loam soil showed that total ionic concentrations were less in the clay soils as evident by significantly lower mean specific conductance. Significantly lower Ca concentrations appear responsible for th lower specific conductance in the clay profile. Two of the plate lysimeters in the sandy profile consistently gave higher concentrations for Mg and Na and corresponingly lower values for Ca and K. This appears to be endemic profile variation and was not found to be significantly different. Thus, monitoring of the most concentrated cations does not differ between lysimeter types at the concentration levels tested with an *in vivo* situation.

The only significant difference was pH. Plate lysimeters consistently collected samples that were .2 to .6 pH units higher. Due to the logarithmic nature of the pH scale, hydrogen ion activity was 1.5 to 4 times greater with the cup samplers. It would appear that selective absorption or screening or hydrogen ions was occurring with the plates and an equilibrium between the soil solution, ceramic plate, and sample solution had not been reached.

Sample contamination is evident in the mean concentrations from tension-free devices presented in Table 2. Magnesium concentrations were the only cations sampled that were not different from cup and plate samples. The inability to sample below rooting-zone depths in loamy sand soils plus the contamination problems with the glasswool polyester fiber will preclude the use of this sampler type in future forest nutrient-loss research.

Table 2. Specific conductance, pH, and cation concentrations collected from two soils using three lysimeter types.

Soil	Lysimeter	Spec. Cond.	Ca	Mg	K	Na	pH
		µmhos/cm	mg/l				
Loamy Sand	Cup	102a[1]	5.8a	2.1a	0.9a	1.6a	5.8a
	Plate	117a	4.1a	3.4a	.4a	1.9a	6.4b
Clay Loam	Cup	60b	1.0b	2.0a	.9a	1.5a	5.9a
	Plate	65b	1.0b	1.9a	1.1a	1.4a	6.1b
	Tension-free[2]	200c	4.1c	2.7a	2.3b	24.3b	7.5c

[1] Means in a column followed by the same letter are not significantly different at the 1% level.

[2] Tension-free data compared to the cup and plate collections in the clay loam soils only.

CONCLUSIONS

The cup lysimeter is the most reliable device for sampling cations, although a bias in phosphate and ammonium sampling has been demonstrated for these samplers (Hansen and Harris 1975; Wagner 1962). If the type of plate lysimeter studied in this investigation is used, then initial samples may not reflect actual soil solution concentrations due to plate adsorption. Plate-collected samples will not reflect accurate concentrations when drastic seasonal changes in soil solution concentrations occur. Cups are easier to install but plates have the distinct advantage of quantifying nutrient loss on an area basis due to the flat shape. The use of both cups and plates is needed to accurately sample cations and given an areal-loss estimate.

LITERATURE CITED

Cole, D. W.
1968. A system for measuring conductivity and rate of flow in a forest soil. Water Resources Research 4:1127-1136.

Gessel, S. P., and D. W. Cole
1965. Influence of removal of forest cover on movement of water and associated elements through soil. J. Am. Water Works Assoc. 57:1301-1310.

Gosz, J. R., and W. J. Dyck
1979. Monitoring the effects of clearfelling on soil nutrient loss. What's New in Forest Research No. 70. For. Res. Inst., Rotorua, New Zealand, 4 p.

Grier, C. C., and D. W. Cole
1971. Influence of slash burning on ion transport in a forest soil. NW Sci. 45:100-106.

Grover, B. L., and R. E. Lamborn
1970. Preparation of porous ceramic cups to be used for extraction of soil water having low solute concentrations. Soil Sci. Soc. Am. Proc. 34:706-708.

Hansen, E. A., and A. R. Harris
1975. Validity of soil-water samples collected with porous ceramic cups. Soil Sci. Soc. Am. Proc. 39:528-536.

Jordon, D. F.
1968. A simple, tension-free lysimeter. Soil Sci. 105:81-86.

Kline, J. R., and C. F. Jordon
1968. Tritium movement in soil of tropical rain forest. Science 160:550-551.

McColl, J. G.
1978. Ionic composition of forest solutions and effects of clearcutting. Soil. Sci. Soc. Am. J. 42:358-363.

McColl, J. G., and D. W. Cole
1968. A mechanism of cation transport in a forest soil. NW Sci. 42:134-140.

Neary, D. G., J. E. Douglass, and W. Fox
1979. Low picloram concentrations in streamflow resulting from forest application of Tordon 10K. Proc. South. Weed Sci. Soc. 32:182-197.

Nutter, W., R. C. Schultz, and G. H. Brister
1978. Land treatment of municipal wastewater on steep forest slopes in the humid southeastern United States. In: Int'l Symp. on State of Knowledge in land Treatment of Wastewater (Hanover, N. H.) p. 265-274.

Parizek, Richard R., and Burke E. Lane
1970. Soil water sampling using pan and deep pressure vacuum lysimeters. J. Hydrology 11:1-21.

Stark, N. M., and C. F. Jordon
1978. Nutrient retention by the root mat of an Amazonian rain forest. Ecology 59:434-437.

Vitousek, P. M., J. R. Gosz, C. C. Grier, J. M. Melillo, W. A. Reiners, and R. L. Todd.
1979. Nitrate losses from disturbed ecosyste
Science 204:469-474.

Wagner, George H.
1962. Use of porous ceramic cups to sample soi
water within the profile. Soil Sci. 94:379-3

Wolff, R. G.
1967. Weathering wood stock granite, near Baltimore, Maryland. Am. J. Sci. 265:106-117

SOILS INTERPRETATIONS FOR SILVICULTURE IN THE SOUTHEASTERN COASTAL PLAIN[1]

R. F. Fisher[2]

Abstract.--Successful intensive silviculture must manage the soil resource wisely. Toward this end, CRIFF has developed a system of soil groups and silvicultural interpretations to be used in pine management in the coastal plain. These are "state of the art" interpretations and are, of course, subject to change as our knowledge increases.

INTRODUCTION

Productivity is an elusive concept. Although the dictionary is straight forward in its definition of the term, the application of the concept to natural resources has taken many forms, and as often as not discussions concerning the maintenance of site productivity never get beyond the definition of terms. The purpose of this paper is to suggest ways of maintaining and enhancing site productivity. I will not even attempt to define productivity. Rather I shall assume that production of wood, water, wildlife, range, and recreation is maximized when the soil resource on any given site is in the best possible condition.

Best possitble condition does not mean a deep, friable, silt loam high in organic matter on every site. It simply refers to the best physical, chemical, and biological conditions that can be expected given the parent material, topographic position, and climate of the site. Thus any operation or treatment that degrades the soil's physical, chemical or biological condition would be deemed detrimental to the maintenance of productivity, and any activity that more or less permanently improves the soil's physical, chemical or biological condition would be considered as enhancing productivity.

One might argue that if we cannot define productivity we cannot measure it, and if we cannot measure it we cannot determine whether or not an activity significantly reduces or enhances productivity. This is true; therefore, we often use easily obtained measures such as cubic feet of wood grown per acre per year to judge the good or ill of management activities. Herein lies a great pitfall. Since we do not possess simple, direct and universally accepted measures of productivity for resources such as water, wildlife, and recreation we often stamp an activity as beneficial and desirable when in fact it degrades the soil and the production of one or more of these imprecisely quantified resources. This is why I have chosen to use soil condition as the key to site productivity even though the analysis of economic returns on the maintenance and enhancement of soil condition is nearly impossible.

Soil Groups

This guide is based on a simple soil group system (Table 1). The soil groups are defined on the basis of drainage class, depth to and nature of the B horizon and the character of the A horizon. The information necessary to place a site into a soil group can easily be obtained in the field or from existing soil survey maps.

These soil groups are intentionally broad. Extremely detailed classification systems lead to many small subdivisions that in practice are too small to treat separately. This soil grouping system usually does not produce an overabundance of small units, yet the system, where it has been applied in the coastal plain, has produced units that are uniform in response to silvicultural treatments (Fisher and Garbett, 1980; Kushla and Fisher, 1980). In other words these soil groups appear to be broad enough to be usable but accurate enough to be useful.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, Nov. 6, 1980.

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Species Selection

The simplest way to increase productivity is to grow the proper species of tree on each site. This is not only true when timber is the resource in question, but it is also true when other resources are considered. For every site, there are one or more tree species that are best at producing timber, wildlife habitat, water yield, etc. Unfortunately a single species or small group of species seldom maximizes the

Table 1.--CRIFF soil group definitions.

Soil Group	Drainage Class	Diagnostic Horizon	Subgroup Equivalents	Representative Series
A	Very poorly to somewhat poorly drained	No spodic horizon; argillic within 20 in.	Typic & Plinthic Aquults	Portsmouth-Bladen
B	Very poorly to somewhat poorly drained	No spodic horizon; argillic below 20 in.	Arenic & Grossarenic Aquults, Aquents & Aquepts	Rutledge-Plummer
C	Very poorly to somewhat poorly drained	Spodic & argillic horizons present	Ultic Aquods & Humods	Mascotte-Sapelo
D	Poorly to moderately well drained	Spodic but no argillic horizon present	Typic, Aeric, & Arenic Aquods & Humods	Ridgeland-Leon
E	Moderately well to well drained	No spodic horizon; argillic within 20 in.	Typic & Plinthic Udults	Goldsboro-Norfolk
F	Moderately well to well drained	No spodic horizon; argillic below 20 in.	Arenic & Grossarenic Udults, Umbrepts & Ochrepts	Blanton-Orsino
G	Somewhat excessively to excessively drained	No spodic horizon; argillic may or may not be present	Psamments	Lakeland-Eustis
H	Very poorly to poorly drained	Organic surface > 20 in. thick	Medisaprists & Histic Humaquepts	Kingsland-Pettigrew

production of all resources. Most often species are selected which will maximize timber production.

In the coastal plain, pines are the preferred species for reforestation. The establishment of large areas of pine plantations in this region is not as detrimental to other resource values as might be expected. This is due to the relative ease with which pines can be established in the coastal plain, and to the large area of land in ponds, drains, etc., which is not converted to plantations.

Table 2.--Recommended species by soil group.

Soil Category	Species in Order of Preference
A	loblolly[1], slash, hardwood
B	slash, loblolly[1], hardwood
C	loblolly[1], slash, longleaf[2]
D	slash, loblolly[1], longleaf[2]
E	loblolly, slash, longleaf
F	slash, loblolly, longleaf
G	longleaf or sand
H	loblolly[1], slash

[1] Loblolly should be used only if adequate phosphorus is supplied.

[2] Longleaf should be used only on better drained soils in the group.

The guide given in Table 2 is very general and should be augmented with local knowledge as to species suitability. Loblolly pine is preferable over slash in soil groups A and C only if phosphorus (P) is applied at time of planting and in areas where the tip moth problem is not severe. Longleaf pine grows well on soil groups C and D sites that are better drained than the average for those groups. Likewise it does well only on the better soil group G sites.

There have been many species comparison tests carried out in the past and the results are quite confusing. Most of these tests were not adequately fertilized nor were the most suitable seed sources always planted. The recommendations in Table 2 are based on the use of the most adaptable seed source, high quality nursery stock, and proper fertilizer treatment.

Harvesting

A major cause of losses in site productivity is soil damage during harvest. This may be hard to believe since the avoidance of such damage appears simple; however, difficulty in managing the cutting operation leads to losses of top soil on thousands of acres each year.

Table 3 presents some limitations for harvest cutting by soil group. In soil groups A and B wet weather logging can cause compaction and surface disturbance which leads to large top soil losses. Staying off these sites during wet weather makes good sense both from a soil management standpoint and from an ease of logging standpoint, but this goal seems hard to reach.

Table 3.--Limitations for harvest cutting by soil group.

Soil Group	Limitation
A	Do not log in wet season.
B	Do not log in wet season.
C	Full tree harvest may reduce residual fertility.
D	Full tree harvest may reduce residual fertility.
E	Do not log in wet season.
F	Few limitations.
G	Few limitations.
H	Choose equipment carefully.

The spodosol soil groups, C and D, are low in organic matter and harvest systems which remove large amounts of debris from the site may seriously lower soil organic matter. Such damage is often not reflected in timber yields, but severely damages understory productivity, browse and forage quality, and increases sediment loss into neighboring streams. Harvest systems that leave logging slash equitability distributed over the site are to be preferred on these soil groups.

The fine textured surface soil in soil group E can easily be compacted if these sites are logged in wet weather. This will reduce yield or lengthen rotation age in the subsequent stand, and can often lead to surface soil loss and increased sedimentation. Although F group soils have more friable surfaces they can also produce a good deal of sediment if sloping soils are badly disturbed.

The H group soils are difficult to log at best. The choice of the proper equipment and operation in the driest season will hold damage to these sites to a minimum. I realize that the foregoing seems oversimplified, and that foresters complain they have no time to oversee nor no power to control logging contractors, but this is an area where we can and must apply better management.

Water Control

Water control or drainage (Table 4) is an important way to improve productivity on many coastal plain sites. Access drainage for road building and harvest activities consists of the construction of roads and their ancillary ditches through low, wet areas. This activity, when improperly carried out, may lead to extensive destruction of terrestrial and aquatic habitat. Such work has all but been stopped by recent legislation and public pressure. This means that large areas in soil groups A, B, C, and H will never be highly productive of timber, range and certain wildlife species.

Table 4.--Water control needs by drainage class within soil groups.[1]

Soil Category	DC[2]	Access Drainage	Silvicultural Drainage
A	0-1	necessary	necessary
	2	necessary	necessary until age 5-10
B	0-1	necessary	necessary until age 5-10
	2	beneficial	beneficial until age 5-10
C	0-1	necessary	necessary until age 5-10
	2	unnecessary	unnecessary
D	0	beneficial	beneficial until age 5-10
	1-2	unnecessary	unnecessary
E,F & G		unnecessary	unnecessary
H	0-1	necessary	necessary

---

[1] Access drainage consists of major ditch networks necessary to lower the water table over large areas. Silvicultural drainage refers to secondary ditch systems intended to lower the water table temporarily over short distances, and bedding or mounding to given new seedlings drainage within the root zone.

[2] DC = drainage class.

In these soil groups, areas that have already been drained can remain productive, with little further environmental degradation, if they are wisely managed. Well regulated water control structures in access drainage systems can moderate high and low flows and reduce siltation from new silvicultural activities.

Silvicultural drainage means small, short term lowering of the watertable to help seedlings become established. Once the trees are established they will transpire enough water to lower the watertable and drainage will be unnecessary. For this reason, interbed trenches or small lateral ditches put in to provide silvicultural drainage should be closed up after 5 to 10 years when the stand of trees begins to control the watertable.

Experiment evidence for the value of such drainage has been contradictory; however, care should be taken in interpreting these results. Often control plots eventually begin to benefit from the drying of the site produced by the treated areas and differences between treated and control areas subside. This delayed response of control areas might never have occurred if it were not for the presence of the treated areas in the same vicinity.

Fertilization with phosphorus can substitute for drainage on some not-so-wet sites but not on all sites. On most wet sites the response to drainage and fertilization with P is more than additive (Tables 5 and 6).

Table 5.--Response of young pine to fertilization and site preparation on coastal savanna sites (Soil groups A and B).

Fertilization	Site Preparation		
	None	Disc	Bed
	------ft^3/A at age 8---		
None	30	80	130
Concentrated superphosphate	90	185	450
diammonium phosphate	120	220	380

Site Preparation

Site preparation is both a great boon and a great bane to productivity. When it is properly done, site preparation creates favorable soil physical and chemical conditions and reduces competition, thus speeding early growth and decreasing the rotation age. When improperly applied, site preparation creates poor soil physical and chemical conditions and reduces growth, while also reducing forage production, causing a loss of

Table 6.--Response of young pine to fertilization and site preparation on flatwoods sites (Soil groups C & D).

Fertilization	Site Preparation None	 Disc	 Bed
	-----ft^3/A at age 8-----		
None	125	160	205
Concentrated superphosphate	135	190	265
diammonium phosphate	185	235	310

wildlife habitat, lessening watershed quality and making the site look horrible. This dicotomy argues strongly for careful application of site preparation treatments.

Foresters have become enamored with machinery and with pine trees; these two facts alone have lead to most of the problems in site preparation. Bigger tractors and cleaner sites are not necessarily better, and overzealous preparation to control hardwoods so that pine can be established generally leads to site deterioration and losses in resource values, even pine production itself.

The treatments recommended in Table 7 are calculated to adequately prepare the site while conserving soil organic matter and fertility and minimizing soil erosion. Such treatment should be beneficial to all resource values save for the temporary loss in visual quality. If the recommended treatment is not adequate to allow for the establishment of pine on some sites, then those sites can not be expected to support pine without the loss of other resource values.

Treatments in the table are in order of preference. The availability of equipment or contractors may dictate some modification in these recommendations. However caution must be taken not to use such factors as excuses for not applying the proper site preparation methods.

Fertilization

The fertilizer recommendations in Table 8 are primarily based on the results of experiments which monitored tree growth and yield. However these treatments should be beneficial to a variety of resources. Limited data from the University of Florida's Cooperative Research In Forest Fertilization Program (CRIFF) files shows a significant improvement in forage and browse on soil group A and C sites fertilized as recommended in Table 6. Watershed and recreational values should also profit from the better soil and vegetation conditions brought about by these treatments. CRIFF experience shows that little fertilizer, aside from that actually applied to water in ditches, streams, etc., ever reaches the runoff water in most fertilized forests. This is due in part to rapid uptake by the vegetation and in part to the fixation of many fertilizer elements in the soil.

Table 7.--Site preparation and regeneration recommendations for pines by soil group.

Soil Group	Preparation
A	chop, burn, chop, double bed, plant chop, burn, disc, bed, plant
B	chop or double chop, double bed, plant chop, burn, disc, bed, plant
C	chop, disc, bed, plant chop, burn, bed, plant
D	chop, bed, plant chop, disc, bed,plant
E	chop, plant chop, burn, plant
F	chop, plant plant in rough
G	chop, plant or seed natural regeneration
H	chop, plant or seed chop, burn, plant or seed

More complex and sophisticated fertilizer formulations than those in Table 8 may be used; however there is little data, as of now, to show that these are more effective than those recommended here.

As can be seen from the probability of response column, not all sites in most soil groups respond to fertilization. Simple soil tests or more complex regression equations developed by Kushla and Fisher (1980) may be used as further checks on the probability of response on a given site.

Soil Test Values Indicative of Responsive Sites

Element	Double Acid Extractable Amount (lbs/A)
Phosphorus	< 8
Potassium	< 20

Table 8.--Recommendations for fertilization at time of planting.

Soil Group	Treatment	Probability[1] of Response	Volume Gain[1] ft^3 A^{-1}Yr^{-1}
A	50 lbs P/A as GRP[5]	100%	+50 to +75
B	50 lbs P/A as GRP, CSP, or DAP[2]	90%	+20 to +40
C	50 lbs P/A as GRP, CSP, or DAP[2]	75%	+15 to +30
D	50 lbs P/A as GRP[2]	75%	-5 to +15
E	50 lbs P/A as DAP	25%	-5 to +15
F	50 lbs P/A as DAP[3]	50%	-5 to +50
G	50 lbs P/A as DAP[4]	50%	-5 to +5
H	50 lbs P/A as GRP or CSP	75%	-5 to +30

[1] Estimated from over 40 CRIFF trials with slash, loblolly, and sand pine.

[2] These sites may benefit from the addition of 50 lbs K/A.

[3] Sites high in quartz sand may benefit from the addition of 50 lbs K/A.

[4] Sand pine only.

[5] GRP = ground rock phosphate, CSP = concentrated superphosphate (triple superphosphate), DAP = diammonium phosphate.

The recommendations in Table 9 are a synthesis of data from CRIFF and the North Carolina State University Forest Fertilization Cooperative (NCSFFC). These treatments are meant to be applied approximately 8 to 10 years prior to harvest in pulpwood or small sawlog rotations and after each thinning in longer rotations. The economics of these treatments in pulpwood rotations are well worked out (Bengtson, 1971). In longer rotations with several thinnings the return on fertilization after the final thinning will far surpass that on fertilization after the first thinning; however, significant production gains in timber volume, as well as other resource values, can be obtained by fertilization after each thinning.

As with recommendations for fertilization at time of planting these recommendations are based largely on tree volume response, but other resource values will also benefit. These broader benefits may call for the use of more complex fertilizers; however, the data on which to recommend such mixtures is almost totally lacking.

If more precision in determining probability of response to fertilization is desired foliar analyses or regression equations (Kushla and Fisher, 1980) may be used.

Critical Foliar Concentrations (%)

	N	P	K	Ca	Mg
Slash Pine	<1.0	<.09	<.30	<.10	<.06
Loblolly Pine	<1.0	<.11	<.30	<.10	<.06

The response, particularly in loblolly pine, may be quite dependent on stand conditions and the guide developed by NCSFFC (Report No. 1) may be used if the stands are to be fertilized without thinning.

Table 9.--Recommendations for fertilization at mid-rotation for pulpwood or after thinning for longer rotations.

Soil Group	Treatment	Probability[1] of Response	Volume Gain[1] $ft^3A^{-1}Yr^{-1}$
A	150 lbs N and 50 lbs P/A[2] as GGRP[3] and urea	100%	45 - 75
B	150 lbs N and 50 lbs P/A[2] as GGRP, CSP, or DAP and urea	90%	20 - 60
C	150 lbs N and 50 lbs P/A[2] as GGRP, CSP or DAP and urea	75%	25 - 55
D	150 lbs N and 50 lbs P/A[2] as GGRP and urea	75%	45 - 90
E	150 lbs N and 50 lbs P/A[2] as CSP or DAP and urea	90%	30 - 50
F	150 lbs N and 50 lbs P/A[2] as CSP or DAP and urea	50%	10 - 40
G	Fertilization not recommended	0%	0
H	150 - 300 lbs N and 50 lbs P/A[2] as GGRP and urea	75%	20 - 60

[1] Estimated from over 50 CRIFF and NCSFFC trials with slash, loblolly and and sand pine.

[2] Stand fertilized with P at time of planting need not be refertilized with P.

[3] GGRP = granulated ground rock phosphate, CSP = concentrated superphosphate (triple superphosphate), DAP = diammonium phosphate.

Conclusion

The southeast and gulf coastal plains are unique in the ease and accuracy with which soil information can be used in silvicultural practice. This is partially due to the rather uniform climate and the very simple soils. However, much of the precision in our ability to use soils as a guide in silviculture comes from the long history of interest in forest soils, and from the many experiments carried out by university-industrial cooperatives, the Forest Service and independent university and industrial scientists.

The majority of the information in this paper has been derived from the observations of the author and/or his interpretation of other's observations or data. The responsibility for the accuracy and truth of these contents is wholly that of the author and not that of any other individual or organization named or unnamed.

The responsibility for improving the accuracy and precision of soils interpretations for silviculture rests not only with the author and other research workers, but also with the foresters who use the information. The best way to test soils interpretations for silviculture is by observation of the results of their use in the field. The feedback from farmers has aided immensely in the development of soils interpretations for agriculture. As these preliminary soils interpretations are used we must observe the results and then further modify our recommendations. In this way we should be able to rapidly refine the recommendations and greatly improve their usefulness.

LITERATURE CITED

Bengtson, George W.
1979. Forest fertilization in the United States: Progress and outlook. J. For. 18: 222-229.

Fisher, R. F. and W. S. Garbett.
1980. Response of semimature slash and loblolly pine plantations to fertilization with nitrogen and phosphorus. Soil Sci. Soc. Amer. J. 44:850-854.

Kushla, J. D. and R. F. Fisher.
1980. Predicting slash pine response to nitrogen and phosphorus fertilization. Soil Sci. Soc. Amer. J. 44(6). In Press.

North Carolina State Forest Fertilization Cooperative.
1979. Predicting fertilizer response in loblolly pine plantations: A model based on site index and basal area. NCSFFC Report No. 1, 27 pp., Raleigh, NC 27650.

RESEARCH ON

ENVIRONMENTAL AND SITE EFFECTS OF FOREST MANAGEMENT PRACTICES IN THE LOWER COASTAL PLAIN[1]

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Abstract.--Integrated research is identified in terms of disciplines, funding sources, and levels of resolution. A research program is described focusing on site and environmental effects of silvicultural management practices ranging from standard pulpwood to short-rotation fuelwood production. Some preliminary data is presented on the pulpwood silviculture studies suggesting first-year negative effects in the poorly drained flatwoods forests. Eucalyptus fuelwood plantings appear to have higher water use.

INTRODUCTION

Research integration aims at focusing several disciplinary teams on a general problem preferably coordinated for one area. The overall research objective is broken down into sub-objectives which are to be achieved by the disciplinary teams in an integrated fashion. Periodic review and communication between teams is required to coordinate levels of resolution for data acquisition and synthesis, methods and units of measurement, and logistics. Integration of different funding sources into one research program can also be accomplished by subcontracting research components to specific interests of funding agencies but within the umbrella of the overall research objective.

This report describes such integration of the latter kind and presents preliminary information from the advanced components of ongoing studies in a research program focused on evaluation of environmental and site effects of intensive forest management practices in the Lower Coastal Plain of Florida.

The overall objective of the research program is to evaluate and predict the environmental and site effects resulting from intensive forest management practices. Environmental and site effects include changes of water blances, nonpoint source pollution, and changes in soil-plant nutrient levels.

The research strategy is a) to impose an intensity range of silvicultural practices on calibrated watersheds to measure hypothesized treatment effects of large-scale operations and, b) to attempt to explain observed treatment effects by measurements of hypothesized mechanisms with more detailed plot studies within the watersheds or elsewhere when appropriate.

Sub-objectives identified are a) evaluation of effects resulting from a range of biomass removal and regeneration operations (Table 1A) and, b) evaluation of effects resulting from fuelwood silviculture in a range of tree-soil-climate conditions of Florida (Table 1B). The latter has two phases: 1) pilot plot studies and 2) small operational watershed studies of promising tree-soil-climate combinations.

The range of biomass removals in watershed scale studies varies from the undisturbed control, to standard pulpwood, to whole-tree, to total living biomass removal. The degree of site disturbance varies from the undisturbed control, to minimum, medium, and maximum soil exposure by standard harvesting-regeneration techniques. Minimum soil exposure is achieved with manual shortwood harvesting, mechanical drum chopping of slash, bedding and planting. Medium soil exposure includes tree-length harvesting, slash burning, chopping, bedding and planting. Maximum soil exposure is achieved with mechanical tree-length harvesting, stump removal, slash burning, windrowing, bedding and planting.

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[1] Paper presented at the Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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The fuelwood silviculture plot trials include six tree species at three locations in Florida. Each species is being evaluated at two high planting densities for growth, yield, site requirements, and environmental effects. In addition, three of the species are also being tested on very small watersheds to assess non-point source pollution and water use effects.

The research program is being supported by funds from half a dozen institutions. The U.S. Forest Service initiated the overall program in 1977 with three isolated watersheds (WS 1-3) ranging from 48 to 136 hectares (IMPAC studies), expanded with a 4-hectare semi-isolated watershed (WS 6) for water quality monitoring of an intermediate intensity level of forestry practices, in Florida's poorly drained flatwood forest land The main objective of this integrated study is t evaluate the impacts of intensive forest management practices on the hydrology and water qualit of Florida's flatwoods ecosystems. Two additional isolated 4-hectare watersheds (WS 4-5) have been constructed with funds from the Oak Ridge National Laboratory (Solar Whole-Tree). The objective of this study is to evaluate the environmental impacts and long-term site degradation of whole-tree harvesting in pulpwood and fuelwood silviculture. A 0.4-hectare waterbed study has been funded by the University of Florida to asse environmental and site effects of coal-ash utilization in Casuarina spp. silviculture. Casuarin is a nitrogen-fixing tree species.

Small 0.01-hectare lysimetric plot studies water use, nutrient requirements, and soil water quality of six fuelwood tree species have been funded by the Department of Energy (Energy and

Table 1.

A. Watershed studies of biomass removal and site preparation effects.

	Biomass Removal			
Soil Exposure	None Control	Pulpwood Stem	Aboveground Stem, crown	Total Stem, crown, stump
None Fire control	WS 3			
Minimum Chopping, bedding		WS 1		
Medium Burn, chop, bed		WS 6	WS 4	
Maximum Burn, windrow, bed		WS 2		WS5, WS 7[1/]

[1/] Note: for fuelwood silviculture with Eucalyptus and Casuarina, respectively.

B. Plot studies of fuelwood species, plant spacing and Florida sites.

Site and species	Plant Spacing (m)		
	2x3	1x1.5	1x0.5
N. Florida			
Sand pine	PL 1	PL 2	PL 3
C. Florida			
Slash pine	PL 4	PL 5	PL 6
Eucalyptus		PL 7	PL 8
S. Florida			
Casuarina		PL 9	PL 10
Eucalyptus		PL 11	PL 12
Melaleuca		PL 13	PL 14

Chemicals from Woody Species). The main objective of this study is to evaluate sand pine in North Florida, slash pine and Eucalyptus viminalis in Central Florida, and E. grandis, Casuarina cunninghamiana, C. equisitifolia, and Melaleuca quinquenervia in South Florida, for high-density fuelwood plantation management and assess associated requirements for soil and water resources.

A waterbalance study of slash pine with a weighing lysimeter has been supported by the Florida Water Resources Research Center since 1978. The objective of this study is to calibrate metereological methods of evapotranspiration assessment which then can be used to independently measure evapotranspiration of the watershed-level waterbalance studies.

PROCEDURES AND PRELIMINARY RESULTS

Watershed Studies

Three large watersheds (WS 1, WS 2, WS 3 in Figure 1) were established in the poorly drained pine flatwoods ecosystems of central Florida during 1977. Isolation was accomplished by road-dike systems and hydrology and water quality monitored with longthroated flumes (Riekerk et al., 1978). Minimum (WS 1), medium (WS 6), and maximum (WS 2) harvesting-regeneration practices were imposed during 1979 and environmental effects compared against control (WS 3) (Riekerk et al., 1980). Water quality data only from the semi-isolated intermediate treatment (WS 6) is included in this report. Hydrologic information from the three isolated watersheds is presented in Table 2 and Figure 2.

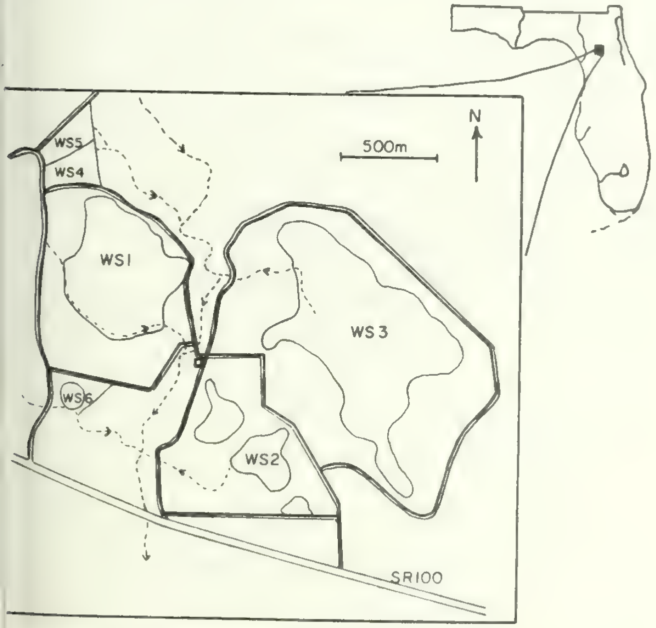

Figure 1. Bradford Forest Watersheds.

Rainfall during the baseline year was somewhat higher than normal due to a few large events. Continuous soil saturation resulted in high water yields (39 percent of rainfall) which normally are less than 10 percent. Groundwater seepage was measured as less than one percent of precipitation input. The maximum disturbance treatment (WS 2) denuded the harvested areas resulting in a 165 percent increase in water yield. The minimum disturbance treatment left significant transpiring vegetation cover which limited the increase of water yield to 66 percent.

Water quality data are summarized in Table 3. With an average coefficient of variation of 40 percent between three watersheds, significance at the 10 percent level of confidence occurs when treatments differ by a factor of 2 from the control. Between-year differences as exemplified by control WS 3 have been accounted for by attaching treatment significance only to differences of between-year ratios.

Treatments did not have any effect on runoff pH, but significantly decreased ammonium-nitrogen levels proportional to treatment intensity. Observed increases of soil solution ammonium levels (Morris and Pritchett, 1980) would suggest significant fixation-sink or gaseous-loss pathways. Treatments had little or no effect on the levels of nitrogen and phosphorus species in runoff waters. Of the cations calcium and potassium levels appeared to be increased by treatments. The increase was highest during the first few months immediately following harvesting operations (Figure 2). Strangely, suspended sediment levels have been increased inversely to soil exposure. Observations of sediments in traps suggest very little movement of bedload.

Water quality data from upland forested watersheds after clearcutting are summarized in Table 4. From this generalized data it is apparent that the Bradford flatwoods forest treatments increased only cation levels in runoff water as compared to upland forest treatments.

Nutrient balance data of precipitation input minus runoff output are summarized in Table 5. Increases in retention are apparent for most cations, especially in maximum treatment WS 2. This suggests fixation by the denuded forest soil to be an important buffer mechanism. Net phosphorus output has been increased from the maximum treatment WS 2 treatment suggesting soil-release processes (more reduced conditions?) to be dominant. The positive balances and the increased retention of cations by severe disturbance suggests these forested watershed ecosystems to be nutrient-poor and of an oligotrophic nature.

In conclusion, it appears that the levels of management intensity increased runoff but decreased ammonium (and nitrate) levels during the first year. Nutrient levels of runoff from the oligotrophic flatwoods forest ecosystems were comparable to treatment effects of upland forested watersheds.

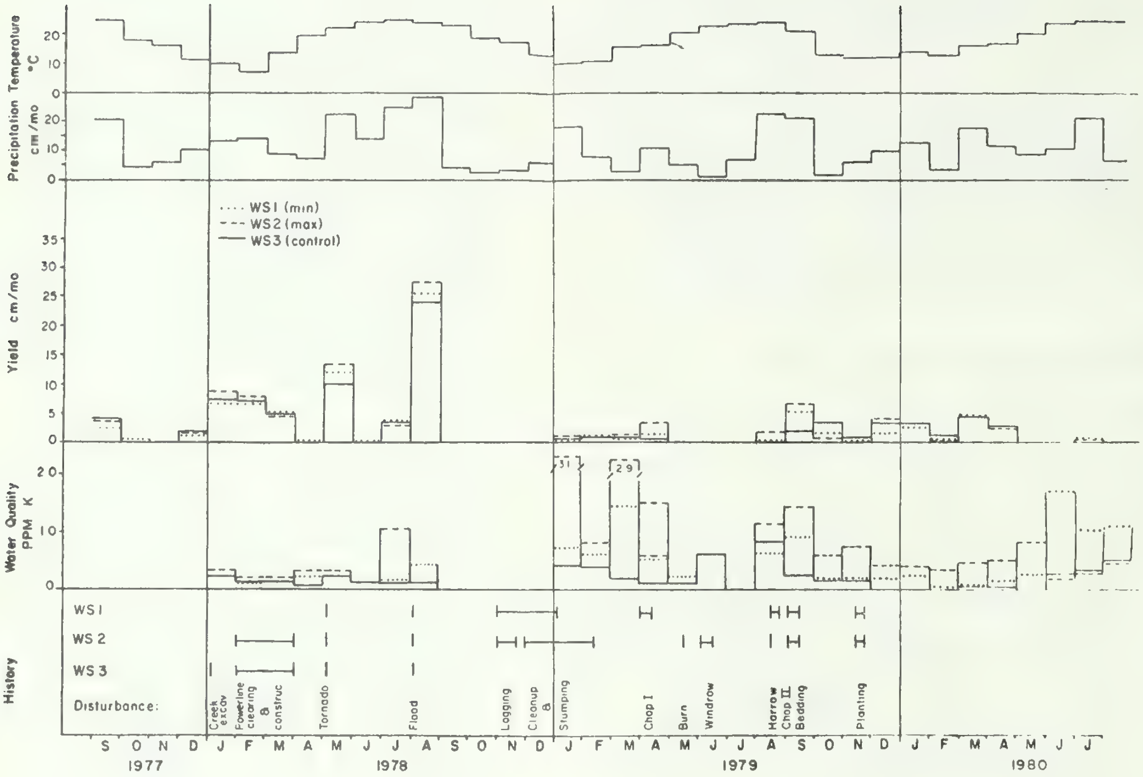

Figure 2. Climate, runoff and water quality patterns of Bradford Forest Watersheds.

Table 2. Hydrologic summary (cm/yr).

	1978 Total WS Observed	1979 Total WS Observed	1979 Total WS Predicted[1/]	1979 Harvested Area	1979 Percent Increase
Rainfall	151.1	129.5	---	---	---
Yield					
WS 1 (Y_1)	58.4	11.4	8.2	13.6	66
WS 2 (Y_2)	62.0	16.4	7.4	19.6	165
WS 3 (X)	56.9	9.2	---	---	---

[1/] From equations for monthly values:

$Y_1 = 1.13\ X - 0.20$ and $Y_2 = 1.28\ X - 0.51$; $R^2 = 0.98$, $S_{\bar{Y}} = 1.0$ cm.

]

Table 3. Runoff water quality comparisons.

		pH	NH_4N	NO_3N	TKN	PO_4P	TP	Ca	Mg	K	Sed
		units	ppm								
Runoff	'78	3.6	0.10	0.03	0.67	0.036	0.04	1.21	0.98	0.28	3.5
WS 1	'79	3.7	0.06	0.03	1.37	0.039	0.02	1.38	0.88	0.61	5.0
Ratio		1.3[1]	0.6[2]	1.0[2]	2.0	1.1	0.5	1.1[2]	0.9[4]	2.2	1.43[2]
Runoff	'78[3]	3.7	0.08	0.02	0.93	0.024	0.06	1.83	0.91	0.30	--
WS 6	'79	3.9	0.07	0.04	1,84	0.033	0.05	1.80	1.50	0.30	--
Ratio		1.6[1]	0.9[2]	2.0	2.0	1.4	0.8	1.0[2]	1.6	1.0	--
Runoff	'78	4.1	0.09	0.02	1.15	0.017	0.11	3.00	1.09	0.48	37.2
WS 2	'79	4.0	0.12	0.05	1.24	0.018	0.02	1.06	1.45	1.30	10.0
Ratio		0.8[1]	1.3[2]	2.5	1.1	1.1	0.2[2]	0.4	1.3	2.7[2]	0.27[2]
Runoff	'78	3.6	0.06	0.01	0.97	0.018	0.04	1.27	0.65	0.13	70.6
WS 3	'79	3.6	0.25	0.03	1.62	0.027	0.02	0.51	1.26	0.15	3.3
Ratio		1.0[1]	4.2	3.0	1.7	1.5	0.5	0.4	1.9	1.2	0.05

[1] Ratio of hydrogen ion concentrations.

[2] Significant treatment effect at the 10 percent level of confidence.

[3] Average of WS 1, 2, 3 data.

Table 4. Runoff water chemistry changes due to clearcutting (ppm).

	NO_3N		P		K		Ca	
	Control	Cut	Control	Cut	Control	Cut	Control	Cut
Florida								
(Hollis et al. 1979)	0.01	0.05	0.03	0.28				
(This paper)	0.03	0.04	0.02	0.03	0.2	0.7	0.5	1.4
Georgia								
(Hewlett 1979)	0.11	0.02	0.34	0.34	1.3	1.3	5.6	2.7
North Carolina								
(Douglass & Swank 1975)	0.005	0.009	0.004	0.004	0.4	0.5	0.6	1.0
West Virginia								
(Aubertin & Patric 1974)	0.10	0.49	0.02	0.04	0.5	0.6	0.8	0.7
(Patric 1980)	0.35	0.41	0.01	0.01	0.7	0.6	1.1	1.0
Pennsylvania								
(Mussalem & Lynch 1980)	0.08	0.37			1.0	1.1	5.8	3.2

Table 5. Nutrient balances (kg/ha/yr).

		NH_4N	NO_3N	TKN	PO_4P	P	Ca	Mg	K	Sed.
WS 1	1978	+2.2	+4.2	+8.4	+0.2	+2.6	+3.7	-1.8	+1.0	-21.0
	1979	+1.8	+2.3	+4.3	0.0	+0.6	+1.3	+2.7	+2.4	-6.4
Min.	Ratio	0.8	0.6	0.5[1]	n.a.	0.2	0.4	0.6	2.4	0.30[1]
WS 2	1978	+2.2	+4.0	+6.1	0.0	+0.5	-4.5	+0.4	+0.4	-153.2
	1979	+1.8	+2.8	+4.7	0.0	+0.3	+1.3	+1.5	+1.8	-17.5
Max	Ratio	0.8	0.7	0.8[1]	n.a.	0.6[1]	0.2[1]	3.8[1]	4.5[1]	0.11[1]
WS 3	1978	+2.2	+4.1	+1.4	0.0	+0.6	+5.9	+1.8	+1.6	-398.6
	1979	+1.7	+3.0	+5.0	0.0	+0.2	+2.3	+1.0	+2.5	-2.7
Control	Ratio	0.8	0.7	3.6	n.a.	0.3	0.4	0.6	1.6	0.01

[1] Significant at the 10 percent level of confidence.

Two smaller adjacent watersheds (WS 4 and WS 5) were constructed during 1980 using road-dike and buried plastic-wall boundaries (Figure 3). Vegetation analyses show a biomass of 104 mt/ha containing 156 kg/ha N, 12 kg/ha P, 30 kg/haK, and 188 kg/ha Ca. The forest floor contains about 290 kg/ha N and 9 kg/ha P, while the rooted soil contains approximately 2300 kg/ha N and 10 kg/ha P (Morris, unpublished data). Apparently most nitrogen is stored in the soil component of the flatwoods forest ecosystem. Preliminary runoff water quality data of these new watersheds are included in Table 6. This information shows some differences with that of the well-established control WS 3 which may be due to recent disturbances from watershed construction. Baseline water chemistry at sampling stations downstream of WS 4 and WS 5 is being monitored to assess watershed treatment effects on stream processing during 1981.

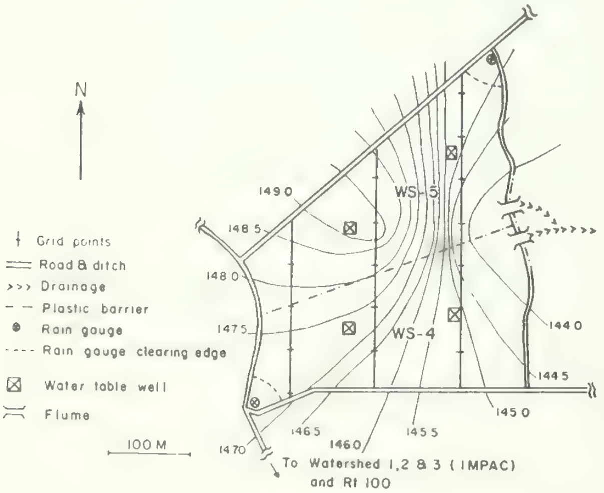

Figure 3. Map of WS 4 and WS 5 of the Bradford Forest research area.

Table 6. Water quality of WS 3, WS 4, WS 5, and downstream sample points.[1]

	TKN	TP	K	Ca	Mg
WS 3	1.01	0.022	0.05	0.30	0.50
WS 4	0.56	0.028	0.20	1.20	1.90
WS 5	0.92	0.034	0.20	1.20	1.10
ST 1	0.72	0.019	0.24	0.47	0.90
ST 2	1.13	0.023	0.30	0.40	0.90
ST 3	1.31	0.020	0.11	0.37	0.93
ST 4	1.12	0.022	0.20	0.77	1.21

[1] Spaced about 100 m. apart.

Two small 0.5-hectare watersheds with plastic wall boundaries are under construction on poorly drained and acid flatwoods soil and will be amended with 100 mt/ha of unweathered coal ash. These areas will be planted in high-density fuelwood spacing with Casuarina spp. during 1981. Soil site and environmental effects, nitrogen fixation by Casuarina, and fuelwood production will be monitored to evaluate the environmental and site impacts of fuelwood silviculture utilizing coal ash amendments.

Plot studies

Smaller lysimetric plots have been developed since 1978 to evaluate the site requirements and environmental effects of fuelwood silviculture with tree species adapted to the different soil and climate conditions of Florida (See Table 1B). Fuelwood silviculture utilizes high-density spacing and very short rotations. Productivity of these stands can be double that of standard pulpwood spacing in short rotations (Table 7).

Table 7. Biomass yields for fuelwood and pulpwood species.[1]

Species	Age (yrs)	Spacing (m x m)	Yield (mt/ha/yr)
Fuelwood			
Slash pine	8	0.6 x 0.6	4.9
Sand pine	6	0.6 x 0.6	7.2
Casuarina	4	1.0 x 1.0	8.3
Melaleuca	3	0.3 x 0.3	13.9
Melaleuca	9	0.6 x 0.6	28.5
Pulpwood			
Eucalyptus	7	2.4 x 2.4	4.5
Slash pine[2]	9	2.7 x 3.7	3.4

[1] Adapted from Conde and Rockwood, 1979.

[2] From Manis, 1977.

Water monitoring in these plots requires ifferent techniques dependent on the site condiions. The deep and excessively drained sandy oils under sand pine in north Florida are being onitored with porous filter tubes at 0.1 atm ension inserted laterally at 2 m depth from a anhole and sub-sampled monthly. Preliminary ata suggest only a few percent of precipitation ercolated during the summer months with no perolation during the drier spring months when oil moisture dropped below 6 percent by weight Figure 4). No effects due to planting density f sand pine is yet apparent in soil moisture egimes.

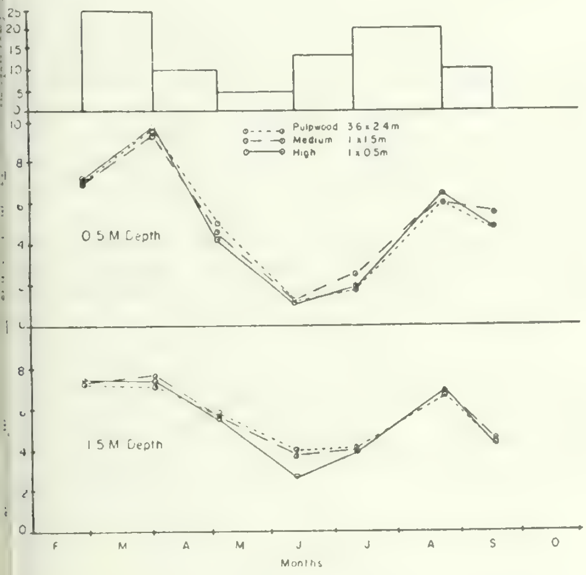

Figure 4. Soil water content in N. Florida sand hills.

The shallow and poorly drained sandy flatwoods soils in North-Central Florida are being monitored with lysimetric plots. Impermeable walls have been constructed down into the underlying clay layer forming an isolated soil monolith (Figure 5). Watertable control and water sampling is with forced drainage. Preliminary watertable data suggest significantly more water use (3 cm) by the high-density (0.5 x 1.0 m) *Eucalyptus* plot than by the low-density (1.5 x 1.0 m) or pulpwood (2.0 x 3.0 m) pine plots. The low-density *Eucalyptus* and high-density pine plots also show more water use, but not significantly so.

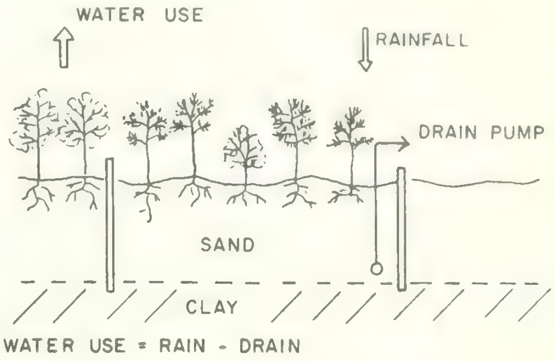

Figure 5. Lysimetric plot diagram.

The deep and poorly drained sandy palmetto-prairie soils in south Florida have been isolated laterally with 1.2 m plastic walls. Monitoring of daily watertable fluctuations provides water-use information (Gray, 1970). Some data has been obtained and no differences in watertable regimes have been observed as of this time.

A small (7.2 m^2) weighing-lysimeter plot has been constructed in the poorly-drained flatwoods soil of north-central Florida and planted to standard pulpwood tree spacing (Figure 6). The hydraulic weighing lysimeter consists of two nested 1.2 m deep fiberglass tanks, the inner one backfilled with soil and provided with forced drainage. Precipitation and weight changes are being monitored continuously to estimate actual evapotranspiration outputs accurately. Equations for calculated potential evapotranspiration rates from adjacent weatherstation data can then be corrected and used for independent evapotranspiration estimates of the large watershed studies. The actual evapotranspiration data from the weighing lysimeter will also be used to check the waterbalances of adjacent lysimetric plots planted in pine pulpwood spacing.

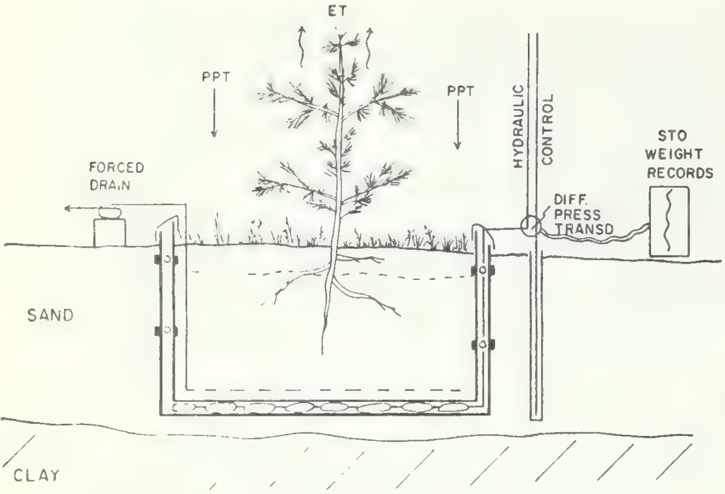

Figure 6. Weighing lysimeter diagram.

CONCLUSIONS

The environmental and site effects research program has been developed with resources from a variety of funding agencies interested in specific aspects of silvicultural impacts. Overlapping use of research facilities provides mutual support reinforcing the data obtained for specific interests. Reporting of results will become more integrated over time with managerial and regulatory applications for silvicultural practices at various levels of intensity.

Preliminary information suggests pulpwood silviculture in the flatwoods physiography to generate lower levels of nitrogen species and higher levels of nutrient cations in runoff water quality. This seems to be the reverse of results reported for upland watershed studies in the northeastern U.S. The water regime of the regenerated sand hill forest in northern Florida appears to be strongly dominated by evapotranspiration losses with only a few percent of precipitation percolating to groundwater. Eucalyptus spp. appears to be performing well in fuelwood experimental plots as compared to other tree species. Some increased effect on water use has been documented so far.

REFERENCES

Aubertin, G. M. and J. H. Patric.
1974. Water quality after clearcutting a small watershed in West Virginia. J. Environ. Qual. 3:243-249.

Conde, L. F. and D. L. Rockwood.
1979. Energy plantation potential in Florida. "Alternative Energy Sources for Florida, Proceedings" Center Envir. Nat. Resour. Program, Univ. Florida:2-12.

Douglass, J. E. and W. T. Swank.
1975. Effects of management practices on water quality and quantity: Coweeta Hydrologic Laboratory, N.C. "Municipal Watershed Management, Proceedings." U.S.D.A. For. Serv. Gen. Tech. Rep. NE-13:1-13.

Gray, D. M.
1970. Handbook on the principles of hydrology. Water Information Center Inc., Huntingdon, N.Y.:p. 3-42.

Hewlett, J. D.
1979. Forest Water Quality: An experiment in harvesting and regenerating Piedmont forest. School For. Resour., Univ. of Georgia, Forest Research Paper:22 p.

Hollis, C. A., R. F. Fisher, and W. L. Pritchett.
1979. Effects of some silvicultural practices on soil-site properties in the Lower Coastal Plains. "Forest Soils and Land Use, Proceedings." 5th N. Am. For. Soils Conf. Dept. For. and Wood. Scie., Colorado State Univ., Ft. Collins, Col.:585-607.

Manis. S. V.
1977. Biomass and nutrient distribution within plantation and natural slash pine stands on wet coastal sites. M.S. thesis Univ. Florida: 72 p.

Morris, L. A. and W. L. Pritchett.
1980. Task 3: Soils and Nutrients. IMPAC Annual Progress Report 1980.

Mussallem, K. E. and J. A. Lynch.
1980. Controlling nonpoint source pollution from commercial clearcuts. "Watershed Management 1980, Proceedings." Am. Soc. Civil Engin. New York:669-682.

Patric, J. H.
1980. Effects of wood products harvest on forest soil and water relations. J. Environ. Qual. Vol. 9:73-81.

Riekerk, H., S. A. Jones, L. A. Morris and D. A. Pratt.
1978. Hydrology and water quality of three small Lower Coastal Plain forested watersheds. Soil and Crop Science Soc. Florida Proceedings 38: 105-112.

Riekerk, H., B. F. Swindel, and J. A. Replogle.
1980. Effect of forestry practices in Florida watersheds. "Watershed Management 1980, Proceedings." Am. Soc. Civil Engin. New York: 706-721.

FOREST AND RANGE INTERACTIONS[1]

Henry A. Pearson[2]

Abstract.--This paper provides information collected on forest, range, and wildlife interrelationships and projects economic values from livestock in the forest program. Data presented are mainly from range research studies, Alexandria, Louisiana, but include some cooperative research and literature review.

INTRODUCTION

Judicious multiple-use planning offers numerous social and economic benefits and requires few concessions from land managers. An important advantage of integrated tree and livestock management is that profit can be higher than with single-resource management. Changing markets encourage flexibility in the overall operation because diversification provides a means of surviving poor markets. Dominant issues in the future will be to overcome commodity shortages--food and fiber--and to protect the environment. Sound multiple-use management of timber lands will enable the landowner to meet both challenges at a profit. However, all disciplines must work cooperatively to accomplish these goals.

The purpose of this paper is to provide information regarding (1) the effects of trees on forage for livestock and wildlife, (2) the effects of cattle on pine regeneration, (3) livestock-wildlife relations, and (4) the economics of adding livestock to the forest program. Hopefully, this paper will show that the forage resource on southern forests is an asset and not a liability. In light of current and future demands on land resources, simultaneous management of timber, livestock, and wildlife is imperative. Southern pine forests have the climate, soils, water, and light necessary to produce good forage and timber (Duvall 1973).

TREES AND FORAGE

Overstory tree density, or canopy, has the greatest influence in determining forage yields. Yields decrease as tree overstory increases (Gaines et al. 1954; Halls and Schuster 1965). In 13- to 17-year-old longleaf and slash pine stands, forage yields decrease about 15 lb/acre for every 1 ft^2 basal area tree increase (Wolters 1973). In 35- to 40-year-old longleaf pine stands, yields decrease about 7 lb/acre for every 1 ft^2 increase (Grelen and Lohrey 1978). Canopy even influences forage nutrients; for instance, forage protein content is higher under shade than in the open (Wolters 1973). Growing cool-season exotics under pine stands does not provide more forage than natives, but can provide green forage during winter when natives are dormant (Pearson 1975).

Any forest management practice that alters the overstory will change forage potentials. Reforestation practices greatly influence the forage available. Wide spacing, such as 10 x 12 ft, or 12 x 12 ft, yield more forage than do closer spacings. Forage yields of 1000 lb/acre were produced through age 16 under slash pines regenerated at 6- x 12-ft spacings (Lewis 1973). Direct-seeded stands usually reduce production sooner than planted stands because trees are generally denser in direct-seeded stands (Pearson et al. 1971; Pearson 1974).

A 12-year-old direct-seeded slash pine stand, precommercially thinned to 500 trees per acre at age 3, produced about four times more forage than unthinned stands (Grelen et al. 1972). If burned and thinned regularly, mature longleaf pine stands provide about half as much forage as treeless range (Grelen and Enghardt 1973; Derr and Enghardt 1969).

Fertilizing the forest to increase tree growth also improves forage quality and yields

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[1] Paper presented at the Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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(McMinn 1966; Lewis 1970; Duvall and Grelen 1967); however, fertilization may not be economical for meeting livestock nutritional requirements (Duvall and Grelen 1967). In fertilized pastures pulpwood yields were 2.7 times more than on nonfertilized range (Burton 1973). Cattle on plots with no trees averaged 0.99 lb daily weight gain (247 lb/acre annually), cattle where trees were spaced 20 x 20 ft gained 0.86 lb daily (178 lb/acre), and those on plots 12- x 12-ft spacings gained 0.77 lb daily (120 lb/acre).

Timber supplies apparently are not greatly reduced even with wider tree spacings. Yields of unthinned slash pine sawtimber were greater from 200 trees/acre after 30 years than from 600 trees/acre thinned to 400 trees at age 15, to 300 at age 20, and to 200 at age 25 (Bennett 1971). At ages 20 to 35 years the cubic yield of 200 trees/acre was over half the yield from 1000 trees, and the yield from 600 trees was 90 to 98 percent of the 1000-tree yield (Bennett 1963).

LIVESTOCK AND PINE REGENERATION

Uncontrolled livestock may graze or trample pine regeneration; however, damage can be reduced or eliminated through management. Guidelines to reduce cattle damage to slash pine (Pinus elliottii Engelm.) regeneration involve mainly prescribed winter rotational burning for livestock distribution and regulation of grazing intensity (Pearson et al. 1971). Planted and direct-seeded slash pine were successfully regenerated with light and moderate grazing intensities. We found only heavy grazing (60 percent utilization of the forage supply) significantly reduced pine survival (about 20 percent in planted stands). Avoiding late winter and spring grazing during establishment and the first year alleviates most of the damage problems even with high stocking rates. Changing the location of supplemental feeding or mineral stations also helps in livestock distribution.

On longleaf pine (P. palustris Mill) regeneration areas in Alabama, moderate grazing by cattle did not harm seedlings during establishment and the first growing season (Boyer 1958). Later observations indicated a decline in longleaf pine survival on grazed range; however, grazing did not follow the guidelines given above (Boyer 1967). Direct-seeded longleaf pine regeneration in Louisiana was highly variable (50 to 1500 trees/acre); however, no significant differences in survival were found between moderately grazed and ungrazed plots (Pearson 1980).

Pines appear highly resistant to grazing damage. In an attempt to simulate grazing damage on pines in Georgia, researchers inflicted several types of injury on slash pine seedlings. It included removing needles, removing the growing shoot, bending the stem horizontally, and stem girdling (Lewis 1980). These injuries were applied in varying degrees and combinations to seedlings at 6, 18, and 30 months after planting. Slash pines--and possibly other pines--apparently recover quickly from most of these injuries. Mortality was high only when all foliage and shoot were removed and stems were bent horizontally (Lewis 1973). Shortleaf (P. echinata Mill.) and loblolly pines (P. taeda L.) browsed within an inch or two of the ground by rabbits survived and grew as well as unbrowsed trees (Wakeley 1970).

In cases where cattle or deer congregate in small openings and seriously damage young pines, livestock populations must be regulated to coincide with forage supplies in the openings. Deferred or seasonal grazing until trees are 8- to 10-ft tall will also reduce damage (Cassady et al. 1955). Preliminary findings on loblolly pine plantations in 40- to 60-acre clearcuts within large site-dominating timber stands (2,000 acres) indicate some losses with continuous cattle grazing. However, natural loblolly pine seedings from trees on the perimeters of the relatively small clearcuts resulted in exceptionally high tree densities on all treatments (Pearson 1980).

Animal repellents such as copper carbonate, tetramethylthiuram (TMTD), or zinc dimethyldithiocarbanate cyclohexylamine (ZAC) help, but have not been completely successful for either deer or cattle (Duvall and Whitaker 1959; Denton et al. 1969). Windrowing debris around vulnerable plantations provides some protection, even against deer.

Some tree benefits may accrue through a multiple-use management program where grazing reduces competition before pine regeneration and removes hazardous fuels (Pearson 1974). The key to success is maintaining a balance between forage and animals and animal distribution.

CATTLE AND DEER

Livestock and wildlife programs can be mutually beneficial. For example, livestock grazing can benefit wildlife by stimulating new growth. Livestock management usually provides water and supplemental feed which may be used by wildlife in times of need (Pearson 1969). Hunting leases can provide an additional source of revenue for the forest landowner. These multiple uses, when properly managed, also foster good public relations in the local community.

When livestock and wildlife exceed food supplies, undesirable competition is created and resources may be damaged. Overuse by livestock for long periods is detrimental to plant composition and yield and can cause soil and site conditions to deteriorate (Duvall and Linnartz 1967). Excessive use by big game will have similar effect and cause damage to nearby agricultural crops.

Several recent studies have sought to determine the extent of overlap in cattle and deer di at different times of the year. In Mississippi pine and pine-hardwood forests, grass use was the most apparent dietary overlap (Mitchell et al. 1979). The major deer diets consisted of mast, mushrooms, grasses, and browse. Although cattle consumed some browse, their diet was composed chiefly of grasses, varying from 77 percent in April to 99 percent in summer and fall.

In Louisiana loblolly-shortleaf pine-hardwood forests, diet overlap between cattle and deer occurs mainly during winter on heavily forested areas or during summer on clearcuts. Fortunately, cattle prefer clearcuts or more open stands where forage abounds rather than the densely timbered stands where it is limited (Thill and Martin 1980). However, few plants shared by deer and cattle contributed more than 1 percent of either diet during any season. On clearcuts with abundant year-round herbage supplies, 88 percent of the cattle diet consisted of grasses and grasslikes (Thill 1980). The deer diet contained 70 to 91 percent browse during fall, winter, and spring, and about 35 percent in summer; grasses and grasslikes in the deer diet were likewise about 35 percent in summer, a significant overlap. On timbered sites, winter and spring diets of both deer and cattle were dominated by browse, but only five species provided 5 percent or more of both their diets. During summer and fall deer diets were mainly browse while cattle diets were grasses and grasslikes. Apparently diet overlaps will be of little significance if cattle stocking rates are determined primarily on grass production.

LIVESTOCK ECONOMICS

Comments that follow are based mainly on cooperative research with Virginia Polytechnic Institute and State University, Blacksburg, VA (VPI) and a presentation given at the New Orleans forest range and pasture symposium (Haney 1980). Cash flow information was processed through several computer programs designed to evaluate long-term forestry investments, and returns are an expression of rewards for the manager's time and capital investments. The internal rate of return and net present value are used to show the economic value from a marginal addition of livestock to the forest program.

To establish a livestock operation on the forest range, certain biological situations, management variables, and investment criteria must be defined because of the infinite number of biological-management combinations available in the South. For instance, biological variables must consider site index, forage production level and forest type. Management variables include herd size, supplementation, and timber site preparation. Investment activities consider initial and replacement costs, annual costs, and returns.

Using 1976 economic levels, 240 potential investment opportunities were 89 percent positive with 84 percent exceeding a 6 percent internal rate of return and some ranging up to 18 percent (Haney 1980). When costs and revenues were adjusted to 1979 levels for a loblolly pine-bluestem site, a variable livestock herd and pasture-supported option, the internal rate of return increased from 14 to 27 percent. Similarly the net present value more than doubled. From 17 years of data collected on the Palustris Experimental Forest in central Louisiana, rates of return varied from 0 to 40 percent depending primarily on cattle price. On a 4800-acre private nonindustrial ownership with 25-year-old slash pine, the rates of return from livestock varied from 5 to 30 percent when cattle prices ranged from $41 to $78 per hundredweight (Westman 1980).

What returns will attract the forest landowner to marginal investments in livestock? Knowledge of the variables involved plus identification of sensitive inputs to obtain appropriate returns will help reduce the risk in making these investments. Livestock economic potentials from any forest land situation can soon be routinely analyzed through a cooperative program maintained by VPI and the State and Private Forestry, U. S. Forest Service, Atlanta, Ga. The investor will still need to understand both the livestock and timber operations, potential problems and the variable markets prior to investment. As stated in the New Orleans symposium, "Attractive opportunities exist, but so do troublesome problems. Otherwise, the woods would be full of cows." (Haney 1980).

LITERATURE CITED

Bennett, F. A.
1963. Growth and yield of planted conifers in relation to initial spacing and stocking. Proc. Soc. Am. For., Atlanta, Ga., Oct. 21-24, 1962, p. 22-26.

Bennett, F. A.
1971. How should pine plantations be thinned? For. Farmer 30(10):6-7, 17-18.

Boyer, W. D.
1958. Longleaf seedlings endure moderage grazing. U.S. Dep. Agric. For. Serv. South. For. Exp. Stn. South. For. Notes 113, 4 p.

Boyer, W. D.
1967. Grazing hampers development of longleaf pine seedlings in southwest Alabama. J. For. 65:336-338.

Burton, G. W.
1973. Integrating forest trees and improved pastures. p. 41-49. In Range Resources of the Southeastern United States. Am. Soc. Agron. Spec. Publ. No. 21.

Cassady, J. T., W. Hopkins, and L. B. Whitaker.
1955. Cattle grazing damage to pine seedlings. U.S. Dep. Agric. For. Serv. South. For. Exp. Stn. Occas. Pap. 141, 14 p.

Denton, D. C., E. H. Hodil, and D. H. Arner.
1969. Prevention and control of damage to trees. In White-tailed Deer in Southern Forest Habitat. Proc. U.S. Dep. Agric. For. Serv. Symp.,

South. For. Exp. Stn., pp. 93-97.

Derr, H. J., and H. G. Enghardt.
1969. Growth in a young managed longleaf pine plantations. J. For. 67:501-504.

Duvall, V. L.
1973. Climatic factors governing forage quantity and quality. p. 19-24. In Range Resources of the Southeastern United States. Am. Soc. Agron. Spec. Publ. No. 21.

Duvall, V. L., and H. E. Grelen.
1967. Fertilization uneconomic for forage improvement in Louisiana pine plantations. U.S. Dep. Agric. For. Serv. Res. Note SO-51, 3 p.

Duvall, V. L., and N. E. Linnartz.
1967. Influences of grazing and fire on vegetation and soil of longleaf pine-bluestem range. J. Range Manage. 20:241-247.

Duvall, V. L., and L. B. Whitaker.
1959. Now! A cattle repellent for pines. Forests & People 9(4):32-33, 46.

Gaines, E. M., R. S. Campbell, and J. J. Brasington.
1954. Forage production on longleaf pine lands of southern Alabama. Ecology 35:59-62.

Grelen, H. E., and H. G. Enghardt.
1973. Burning and thinning maintain forage in a longleaf pine plantation. J. For. 71:419-420.

Grelen, Harold E., and Richard E. Lohrey.
1978. Herbage yield related to basal area and rainfall in a thinned longleaf plantation. U.S. Dep. Agric. For. Serv. Res. Note SO-232, 4 p.

Grelen, H. E., L. B. Whitaker, and R. E. Lohrey.
1972. Herbage responses to precommercial thinning in direct-seeded slash pine. J. Range Manage. 25:435-437.

Halls, L. K., and J. L. Schuster.
1965. Tree-herbage relations in pine-hardwood forests of Texas. J. For. 63:282-283.

Haney, Harry L., Jr.
1980. Economics of integrated cattle-timber land use. In Proc. South. For. Range and Pasture Resour. Symp. p. 165-183. [New Orleans, La. March 13-14, 1980.]

Lewis, C. E.
1970. Responses to chopping and rock phosphate on south Florida ranges. J. Range Manage. 23:276-282.

Lewis, C. E.
1973. Integrating management of forest and range resources. p. 69-78. In Range Resources of the Southeastern United States. Am. Soc. Agron. Spec. Publ. No. 21.

Lewis, C. E.
1980. Simulating cattle damage to young slash pine. Abstr. of Papers, 33rd Annu. Meeting, Soc. for Range Manage. San Diego, Ca. Feb. 11-14, 1980. p. 46.

McMinn, J. W.
1966. Phosphate aids tree growth. Fla. Cattleman and Livestock J. 30(8):44-45.

Mitchell, W. A., H. A. Jacobson, and M. Gray.
1979. Preliminary results on cattle and deer relationships in the southeastern pine forests. Abstr. of Tech. Papers, 2nd Annu. Meeting. Southeast Deer Study Group, Mississippi State, Ms., Feb. 7-9, 1979, p. 12-13.

Pearson, Henry A.
1969. Starvation in antelope with stomachs full of feed. U.S. Dep. Agric. For. Serv. Res. Note RM-148, 4 p.

Pearson, H. A.
1974. Range and wildlife opportunities. In Proc. Symp. on Management of Young Pines. U.S. Dep. Agric. For. Serv. Southeast. Area, State and Private For., South. and Southeast. For. Exp. Stns. p. 19-27.

Pearson, H. A.
1975. Exotic grass yields under southern pines. U. S. Dep. Agric. For. Serv. Res. Note SO-201, 3 p.

Pearson, Henry A.
1980. Livestock in multiple-use management of southern forest range. In Proc. South. For. Range and Pasture Resour. Symp. p. 75-88. New Orleans, La. March 13-14, 1980.

Pearson, H. A., L. B. Whitaker, and V. L. Duvall.
1971. Slash pine regeneration under regulated grazing. J. For. 69:744-746.

Thill, R. E.
1980. Cattle and deer diets on forested and clearcut pine-hardwood sites in Louisiana. Abstr. of Papers, 33rd Annu. Meeting. Soc. fo Range Manage., San Diego, Ca, Feb. 11-14, 198 p. 47.

Thill, Ronald E., and Alton Martin.
1980. Deer and cattle diet overlap in Louisiana pine-hardwood forests. Proc. 33rd Annu. Conf. Southeast. Assoc. of Game and Fish Comm. p. 66-71. Hot Springs, Ar. Oct. 21-24, 1979.

Wakeley, P. C.
1970. Long-term effects of damage by rabbits t newly planted southern pines. Tree Planters' Notes 21(2):6-9.

Westman, W. W.
1980. Economic guidelines for adding beef cattle to pine-timbered range in the South. Unpublished M. S. Thesis. Department of Forestry, Virginia Polytechnic Institute and State University, Blacksburg, Va. 161 p.

Wolters, G. L.
1973. Southern pine overstories influence herbage quality. J. Range Manage. 26:423-426

FORAGE AND PINE GROWTH WITH CLEARCUTTING AND SITE PREPARATION[1]

John J. Stransky and Lowell K. Halls[2]

Abstract.--Total available forage yield on three loblolly-shortleaf pine-hardwood forest sites in east Texas was sampled before clearcutting and one, three, and five growing seasons after planting site preparation. All sites were planted with 1-0 loblolly pine seedlings. Total forage yield averaged 345 kg/ha in the uncut forest. Yields peaked the first summer after site preparation on the untreated control (3294 kg/ha), burned (3719 kg/ha), and chopped plots (3416 kg/ha), and in the third year on the KG-bladed plots (3167 kg/ha). By the fifth growing season total forage yield declined to 1016, 1434, 1796, and 2132 kg/ha, respectively. After five growing seasons, pine survival averaged 87 percent on KG plots, 79 percent on chopped, 63 percent on burned, and 57 percent on control plots. Mechanical site treatments resulted in better pine height and diameter growth than the burned and control treatments.

INTRODUCTION

Clearcutting, site preparation, and planting are efficient means of harvesting and regenerating southern pines. However, there is considerable disagreement as to how these silvicultural practices affect other land uses and values.

The present study was conducted to find out how forage yields, plant species composition, and the growth of planted pines are affected by various site preparation methods after clearcutting of timber on pine-hardwood forest sites of east Texas. These data are needed to help clarify the effects of silvicultural operations on wildlife habitats.

Temple-Eastex Incorporated of Jasper, and International Paper Company of Nacogdoches, Texas, provided land, machinery, and manpower to establish and maintain this study.

STUDY SITES

All three study sites are within the loblolly-shortleaf pine-hardwood forest type that covers nearly 28 million ha in the southern U.S., and reaches its westernmost extension in east Texas (Stransky 1976). All sites supported mature pine-hardwood stands before clearcutting in the fall of 1972.

The sites are part of the Gulf Coastal Plain's Quaternary deposits, which are underlain by sands, sandstones, and clays of the Tertiary's Oligocene period (Dumble 1918). Their topography is nearly level to gently sloping.

Site 1 is about 24 kilometers south of Nacogdoches, Texas, on the Stephen F. Austin Experimental Forest. The site has never been cleared for agriculture, and, based on ring counts, the timber had remained uncut for at least 50 years. Interspersed with the pines were several hardwoods as old as 117 years; the majority though were about 80 years of age. Tree basal area averaged 38 m^2/ha; 31 m^2 in pine and 7 m^2 in hardwood.

The principal pine species were loblolly pine (Pinus taeda L.) and shortleaf pine (P. echinata Mill.) in admixture with southern red oak (Quercus falcata Michx.), sweetgum (Liquidambar styraciflua L.) and winged elm (Ulmus alata Michx.).

Prominent among shrubs were American beautyberry (Callicarpa americana L.) and blackberry

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980

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(Rubus spp.). Virginia creeper (Parthenocissus quinquefolia (L.) Planch.), grape (Vitis spp.), and greenbriers (Smilax spp.) were among the most prominent vines. Vines made up 82 percent of the understory small stems, other hardwoods 9 percent, oaks 4 percent, shrubs 4 percent, and pines 1 percent. Longleaf uniola (Uniola sessiliflora Poir.), elephant's foot (Elephantopus tomentosus L.) and twinberry (Mitchella repens L.) were common herbaceous plants.

Site 2 is near Wells, in Cherokee County, and is owned by International Paper Company. It is 16 km due west of site 1 (Nacogdoches County). The area was cleared for agriculture around 1890 and was cultivated until about 1930. The abandoned land was invaded by pines. Several hardwoods on the site were as old as 85 years, the majority being about 45 years of age. Tree basal area averaged 21 m^2/ha; 11 m^2 in pine and 10 m^2 in hardwood.

The prevalent pine species were loblolly pine and shortleaf pine. These occurred together with southern red oak, post oak, water oak, sweetgum, and winged elm.

Principal shrubs were American beautyberry and blackberry. Virginia creeper, grapes, and greenbriers were the most prominent vines. Vines made up the greatest proportion of small stems (35 percent), followed by shrubs (33 percent), other hardwoods (17 percent), oaks (12 percent), and finally pines (3 percent). Most common herbaceous plants were longleaf uniola, pinehill bluestem (Andropogon spp.), and panic grasses (Panicum spp.).

Site 3 is about 80 km southeast of site 1 near Jasper, in Jasper County, Texas. It is owned by Temple-Eastex Incorporated. The site had never been cleared for cultivation but it had been grazed by livestock. The area supported a 45-year-old forest stand. Tree basal area averaged 24 m^2/ha; 18 m^2 in pine and 6 m^2 in hardwoods.

The principal tree species of the overstory were loblolly pine, shortleaf pine, southern red oak, water oak, post oak, willow oak (Quercus phellos L.), sweetgum, and blackgum (Nyssa sylvatica Marsh.).

The midstory was about 30 years old, consisting mainly of the same species as the overstory, plus American holly (Ilex opaca Ait.), red maple (Acer rubrum L.), mockernut hickory (Carya tomentosa Nutt.), and flowering dogwood (Cornus florida L.).

Common shrubs were American beautyberry, yaupon (Ilex vomitoria Ait.), blackberry, blueberry (Vaccinium spp.), and southern wax-myrtle (Myrica cerifera L.). Prevalent vines were yellow jessamine (Gelsemium sempervirens (L.) Ait.), muscadine grape (Vitis rotundifolia Michx.), and greenbriers. Vines made up 47 percent of the understory stems, shrubs 34 percent, other hardwoods 10 percent, oaks 6 percent, and pines 3 percent. Longleaf uniola, elephant's foot, and twinberry were the most abundant herbaceous plants.

METHODS

Site Treatments

The study had a randomized block design consisting of three adjacent blocks and four site treatments on each of the three sites. Individual site treatment plots were 0.6 ha squares. After the merchantable trees were cut and removed from the three study areas in the fall of 1972, the following site preparation treatments were applied during February and March 1974 on site 3, and during August and September 1974 on sites 1 and 2:

Control--No site preparation, all woody stems greater than 2.5 cm in diameter at breast height (dbh) were cut.
Burn--all stems greater than 2.5 cm dbh were cut and burned with the logging slash by head fires.
Chop--logging slash and all stems were cut with a chopper and burned.
KG--all stems were cut with a KG blade, and the logging slash was raked off the plots and burned. Sites 1 and 2, but not site 3, were cultivated with a heavy-duty disk after having been KG bladed.

The sites were handplanted with 1-0 loblolly pine seedlings at 2.4 by 3 m spacing. Site 3 was planted in mid-March 1974, and sites 1 and 2 in February and March 1975.

Vegetation Measurements

In the summer of 1972 and 1973 before and one year after timber cutting, the vegetation on all three sites was inventoried and forage yield sampled on 20 1-m^2 quadrats equally spaced within the central 0.4 ha of each 0.6 ha plot. The inventory and forage yield sample was again taken one, three and five growing seasons after site preparation. Site 1 was sampled in the summers of 1975, 1977, and 1979; site 2 only in the summers of 1975 and 1977; site 3 in the summers of 1974, 1976, and 1978. The annual growth of all herbaceous and woody plants was clipped up to a height of 1.5 m, dried at 70° C, and weighed to the nearest 0.1 g. We grouped these data to show yields in kilograms per hectare (kg/ha) for herbage (grasses, grasslike species, legumes, composites, and other forbs), and browse (pines, oaks, other trees, shrubs, and vines). Plant nomenclature followed Gray's Manual of Botany (Fernald 1970).

Pine seedling survival was tallied on randomly selected rows at all three sites at the end of the first and the fifth growing seasons after planting. Tree heights and diameters (dbh) were measured after the fifth growing season, and observations were made on crown class and insect damage.

For all data, differences among treatments were tested by analysis of variance at the 0.05 level of significance, and by Duncan's test.

RESULTS AND DISCUSSION

Forage Yield

Before Clearcutting (1972)

On site 1 total forage yield in the uncut timber ranged from 258 to 356 kg/ha, averaging 328 kg/ha. Of this 232 kg/ha were browse (70 percent), and 96 kg/ha were herbage -- mostly grass (30 percent). Thus, available browse greatly outweighed herbage (Table 1).

Species contributing most to browse yields were mockernut hickory, flowering dogwood, sweetgum, poison ivy (Rhus radicans L.), and rusty blackhaw (Viburnum rufidulum Raf.). Longleaf uniola contributed 79 percent of the total herbage yield.

On site 2 total forage yield ranged from 287 to 384 kg/ha, averaging 347 kg/ha. On this formerly cleared site, browse species contributed only 40 percent of the total forage, mostly Virginia creeper, greenbriers, post oak, sweetgum, winged elm, and American beautyberry. Longleaf uniola contributed 54 percent of the herbage. Along with panic grasses, pinehill bluestem, and longleaf uniola, grasses amounted to 68 percent of the total herbage.

On site 3 total forage yield ranged from 309 to 383 kg/ha, averaging 359 kg/ha. Browse species averaged 86 percent of the total, mostly yaupon, yellow jessamine, and sweetgum. Longleaf uniola, twinberry, and elephant's foot constituted 91 percent of the herbage yield.

After Clearcutting (1973)

On site 1, one growing season after clearcutting, forage yields ranged from 1330 to 2058 kg/ha, averaging 1714 kg/ha; a fivefold increase over the uncut stand. The most obvious feature of the post-cutting yield pattern in 1973 was the great increase in grasses and other herbaceous plants (Table 1).

The greatest total yields were obtained on the control and burned plots from which small pines and culls were cut by hand soon after the merchantable overstory was harvested. The KG and chop plots yielded less total forage because they still contained leftover cull trees. The proportion of herbage too, was less on these plots than on the other treatments.

Browse species contributing most to forage yield were American beautyberry, Virginia creeper, grapes, southern red oak, sweetgum, and winged elm.

Table 1.--Forage yield by sites, site treatments, and sampling dates

Forage	Control					Burn					Chop					KG				
	Before cut	After cut	Years after site preparation			Before cut	After cut	Years after site preparation			Before cut	After cut	Years after site preparation			Before cut	After cut	Years after site preparation		
			1st	3rd	5th			1st	3rd	5th			1st	3rd	5th			1st	3rd	5th
	kg/ha																			
SITE 1																				
Browse	168	1022	1722	1473	745	244	1045	1748	1654	885	248	978	1592	1871	1087	267	812	303	698	1003
Herbage	90	1036	1558	743	184	105	767	2274	942	299	102	680	1914	1152	352	89	518	2536	2431	951
Total	258	2058	3280	2216	929	349	1812	4022	2596	1184	350	1658	3506	3023	1439	356	1330	2839	3129	1954
SITE 2																				
Browse	110	297	877	842	--	196	373	747	908	--	152	273	390	808	--	104	394	144	334	--
Herbage	247	1092	2940	1242	--	164	1163	2850	1098	--	135	450	3299	1847	--	280	790	2398	2265	--
Total	357	1389	3817	2084	--	360	1536	3597	2006	--	287	723	3689	2655	--	384	1184	2542	2599	--
SITE 3																				
Browse	310	2356	1955	1612	1007	339	2007	1737	2098	1429	324	876	497	1823	1765	266	911	524	1267	1405
Herbage	72	561	829	371	96	22	524	1803	1029	254	59	1257	2556	1796	389	43	375	2411	2507	906
Total	382	2917	2784	1983	1103	361	2531	3540	3127	1683	383	2133	3053	3619	2154	309	1286	2935	3774	2311

The dominant herbaceous species were panic grasses and longleaf uniola. Other herbs showing large increases were sedges (Carex spp.) and dogfennel (Eupatorium capillifolium (Lam.) Small).

On site 2, total forage yield ranged from 723 to 1536 kg/ha, averaging 1208 kg/ha; a threefold increase over the uncut forest. Herbs increased more than browse on this formerly cleared site.

Browse species contributing most to forage yield were American beautyberry, post oak, and sweetgum. Panic grasses were the dominant herbaceous species. Other herbs showing large increases were pinehill bluestem, longleaf uniola and sedges.

On site 3, total forage yields ranged from 1286 to 2917 kg/ha, averaging 2217 kg/ha; a sixfold increase over the uncut forest. Herbs increased proprtionately more than browse plants, and constituted 31 percent of the total forage. Yields of both browse and herbage were relatively low on plots that were to be KG bladed because these plots, unlike the others, carried many leftover culls and small trees throughout the 1973 growing season.

Browse species contributing most to forage yield in 1973 were American beautyberry, blackberries, grapes, willow oak, and sweetgum. Panic grasses replaced longleaf uniola as the dominant herbaceous species. Other herbs showing large increases were sedges, rushes (Juncus spp.) and the composites fleabane (Erigeron spp.), dogfennel, and wild lettuce (Lactuca canadensis L.).

After Site Preparation

Total available forage yield peaked the first growing season following site preparation on the control, burn, and chopped treatments on all three sites (Table 1). The sole exception was the control on site 3 which peaked the year after clearcutting.

By and large on all three sites the total forage yield was similar the first year after site preparation for the control, burn, and chopped plots, but the proportion of browse and herbage varied between sites and site treatments. Sites 1 and 3 generally produced more browse than herbage. The formerly cleared site 2 produced much greater quantities of herbage than browse.

With one exception (KG treatment on site 3) herbage yields peaked the first growing season after site preparation. With gradual closure of the pine canopy and an increase in the height and density of other woody plants, herbage yields decreased. The decrease was faster on treatments that did not reduce the number of woody plants drastically (control and burn). Herbage decline was slow on chopped plots and especially on KG plots where many woody plants were eliminated or greatly reduced in size.

On the chopped plots, available browse increased up to the third growing season but decreased by the fifth. The reason for the third season increase was the recovery of woody plants from the effects of chopping. By the fifth season many woody plants had grown beyond the 1.5 m height limit that is easily accessible to deer (Odocoileus virginianus).

On the KG bladed plots total forage yield was greatest in the third growing season. Browse was still increasing by the end of the fifth growing season as woody plants continued to recover from the effects of blading, but herbage yield declined. By the end of the fifth season the average total forage yield was directly proportional to site preparation intensity and ranked: control (1016 kg/ha), burn (1434), chop (1796), and KG (2132 kg/ha).

Pine Survival And Growth

KG blading drastically reduced woody plant numbers and resulted in the highest pine survival on all three sites, being 91, 73, and 97 percent (Table 2). The chopping treatment attained the nex highest survival with 83, 64, and 90 percent. Burning produced good survival (85 percent) on site 3 which was burned under very favorable wind and fuel moisture conditions. Survival on sites 1 and 2 was low because the fires did not carry as well and woody plant numbers were not reduced below that on control plots. Pine seedling survival on control plots averaged 57 percent, the lowest of all treatments.

Table 2.--Survival of planted pines after five growing seasons

Location	Site treatments			
	Control	Burn	Chop	KG
	percent			
Site 1	55	63	83	91
Site 2	52	41	64	73
Site 3	63	85	90	97
Mean	57	63	79	87 1/

1/ Values connected by the same line are no statistically different at the 0.05 level of probability.

Generally, seedling survival was poorest on the dry soils of site 2. Survival on sites 1 and 2 that were planted in spring 1975 was not as good as on site 3 which was planted in spring 1974. A rainy growing season followed in 1974 and was in contrast to the hot dry summer of 1975.

The severity of woody plant competition to planted pines is shown by the high percentage of pines that were overtopped by hardwoods and shrubs on the control and burned plots (Table 3). By contrast only few pines were overtopped on chopped plots and even less on KG bladed plots.

Table 3.--Planted pines overtopped by hardwoods

Location	Site treatments			
	Control	Burn	Chop	KG
	percent			
Site 1	43.2	41.2	7.2	0.7
Site 2	14.9	27.2	8.9	0.9
Site 3	32.3	9.0	0.7	1.0
Mean	30.1	25.8	5.6	0.9 1/

1/ Values connected by the same line are not statistically different at the 0.05 level of probability.

Height growth of pines was significantly better on KG bladed and chopped plots than on the control and burned plots (Table 4). Trees that grew tallest also had the greatest diameters (dbh). Several studies showed that the early advantages in growth due to site preparation are maintained for a long period in the life of the young stand, possibly through its entire expected rotation (Wagenknecht 1941, Stransky 1964, Schultz 1975).

Table 4.--Height of planted pines after five growing seasons

Location	Site treatments			
	Control	Burn	Chop	KG
	cm			
Site 1	285	290	355	410
Site 2	299	251	321	331
Site 3	306	305	370	311
Mean	297	282	349	351 1/

1/ Values connected by the same line are not statistically different at the 0.05 level of probability.

Nantucket tipmoth (Rhyacionia frustrana Comstock) severely damaged the growing tip of pines on all three sites and could have caused some growth losses. The damage averaged 76, 73, and 74 percent for sites 1, 2, and 3. Both mechanized site treatments showed 69 percent damage, 71 percent on controls, and 89 percent on burned plots. Possibly the initial rate of infestation was the same with all site treatments, but the more vigorous trees on chopped and KG plots appeared to have outgrown the visible signs of tipmoth damage by the fifth growing season.

SUMMARY

Total forage production averaged 345 kg/ha in the uncut timber stands. Differences between site and treatment plots were not significant.

After clearcutting, yields increased several fold. The least increase was on the KG and chopped plots that still supported unmerchantable trees.

Yields peaked the first year after site preparation on all treatments and sites except the KG plots, which peaked the third year.

Five years after site preparation the average forage yields on sites 1 and 3 had declined, but they were still about five times greater than they had been in the uncut forest. The yields were in direct proportion to intensity of site preparation.

On site 2, the area previously cultivated, the browse/herbage proportion was relatively low before and after site preparation. The opposite was true on sites 1 and 3 for the control and burn treatments. On the mechanical treatment plots the browse/herbage ratio was low the first few years after treatment but relatively high the fifth year.

Pine survival, height and diameter growth averaged highest on the KG bladed plots from which most of the non-pine woody vegetation was eliminated, followed by chopping, burning and control.

Continued observations will tell how long the forage production can be maintained by the various site treatments to support wildlife and how much the treatments affect pine tree growth in the long run.

LITERATURE CITED

Dumble, E. T.
1918. The geology of east Texas. Univ. Texas Bull. 1869. 388 p.
Fernald, M. L.
1970. Gray's manual of botany. Ed. 8. Van Nostrand Reinhold Co., New York, 1632 p.
Schultz, R. P.
1975. Intensive culture of southern pines: Maximum yields on short rotations. Iowa State Jour. Res. 49(3), Pt. 2:325-337.
Stransky, J. J.
1964. Site preparation effects on early growth of loblolly pine. Tree Planters' Notes 64:4-6.

Stransky, J. J.
1976. Vegetation and soil response to clearcutting and site preparation in east Texas. Ph. D. Dissertation, Texas A&M Univ. 193 p.

Stransky, J. J. and L. K. Halls.
1978. Forage yield increased by clearcutting and site preparation. Proc. 32nd Annu. Conf. Southeastern Assoc. of Fish and Wildlife Agencies. 32:38-41.

Wagenknecht, E.
1941. Uber den Einfluss verschiedener Bodenbearbeitungsverfahren auf das Wachstum von Kiefernkulturen. Z. Forst- und Jagdwes. 73:297-342.

EFFECTS OF SILVICULTURAL PRACTICES ON BIRDS IN A NORTH FLORIDA FLATWOODS[1]

Lesley A. Rowse[2] and Wayne R. Marion[3]

Abstract.--Avian community composition was monitored before and after clearcutting and post-harvest treatments in North Florida flatwoods, Bradford County, Florida from June 1977 to February 1980. Several new species were attracted to cleared areas. A few bird species that overwintered in the flatwoods increased in density on the treatment sites after harvest. Use of the treatment areas after harvest by breeding species was primarily confined to cypress/bay habitats. Practices which may be beneficial to flatwoods avifauna in areas being managed for pulpwood production are leaving cypress/bay habitats intact in areas being harvested, creating windrows in clearcuts, leaving snags standing, and allowing some understory development in plantations.

INTRODUCTION

Since 1952, private forest industry has inreased its timberland holdings in Florida by .4 million ha (U.S. Department of Agriculture 978). The majority of this land is in North lorida and is managed for slash pine (*Pinus lliottii*) production.

The consequences of intensive forest manageent practices on the indigenous North Florida latwoods avifauna have been poorly documented. tudies conducted on the effects of forest manageent practices on avian communities in other reas have shown varying results. Noble and amilton (1975) assessed avian community compotion in a mature uneven-aged pine-hardwood stand d compared it with 3 stages of even-aged loblolly ne (*Pinus taeda*) plantations. They observed that from 2 to 10 times more birds inhabited the mature stand than inhabited the even-aged plantations. Conner (1979) found the overall effects of clearcutting mature stands of pine-oak in Virginia to be detrimental to the avian community. These studies generally indicate that avian density and diversity increase as a forest stand matures. However, other studies imply that avian density and diversity reach their peak a few years after clearcutting and diminish as the stand matures. In pine flatwoods of Mississippi, greater numbers of bird species and individuals occurred in younger pine plantations than in the interior of uncut, mature stands (Perkins 1973). Winter densities of birds in different aged pine stands in Texas were greatest in the small sapling stage (Dickson and Segelquist 1977).

Most studies have assessed only the impacts of forestry on overall density and diversity. While avian density and diversity may increase on sites managed for slash pine production, bird species composition may be substantially altered (McArthur and Whitmore 1979). Cleared areas may be more attractive to birds seeking early successional habitats, but be unattractive to avian species specialized for a more mature forest. Therefore, determination of bird species composition in both managed and unmanaged areas is helpful in understanding impacts of forest management practices on indigenous avifauna.

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Objectives of this study were to determine the number of avian species and individuals utilizing a North Florida flatwoods prior to and after harvesting and site preparation and to recommend practices to minimize the possible adverse effects of forest management practices on the native avifauna.

This study was part of a larger investigation that is attempting to determine the effects of forest management practices on an array of forest resources (IMPAC - Intensive Management Practices Assessment Center). IMPAC is an ongoing project sponsored by the U.S. Forest Service. The cooperation of Container Corporation of America, Starke, Florida, in providing study sites and treatments, is gratefully acknowledged.

Study Area

This study was conducted on 3 contiguous, experimental watersheds in Bradford County, approximately 5 km west of Starke, Florida (Figure 1). Prior to its purchase by Container Corporation of America in 1938, Empire Lumber Company owned and managed the land for sawtimber. The tract was cut in about 1950 and regenerated itself naturally (T. Cremer, pers. comm).

Pine flatwoods dominated the regenerated tract, which also was interspersed with cypress (*Taxodium distichum*) ponds. The canopy of the pine areas was comprised of slash pine and scattered longleaf pines (*Pinus palustris*). Major understory species in the pine areas were gallberry (*Ilex glabra*), wax myrtle (*Myrica cerifera*), and saw palmetto (*Serenoa repens*). Cypress ponds had variable canopies ranging from a predominance of cypress to a combination of cypress, loblolly bay (*Gordonia lasianthus*), and blackgum (*Nyssa sylvatica*). Ponds comprised solely of a cypress overstory typically had a closed canopy and a more open understory. Major understory species in these sites were myrtle-leaved holly (*Ilex myrtifolia*) and St. Johnswort (*Hypericum brachyphyllum*). Sites that were comprised of cypress, bay, and blackgum had a more open canopy which allowed for a lush understory of fetterbush (*Lyonia lucida*) and greenbriar (*Smilax* spp.).

In November 1978, Watersheds 1 and 2 were harvested (Table 1) and Watershed 3 was left intact to serve as a control. A total of 59 percent of Watershed 1 and 74 percent of Watershed 2 were cut (Riekerk et al. 1980). The cypress/bay areas were left intact during application of harvest and site preparation practices.

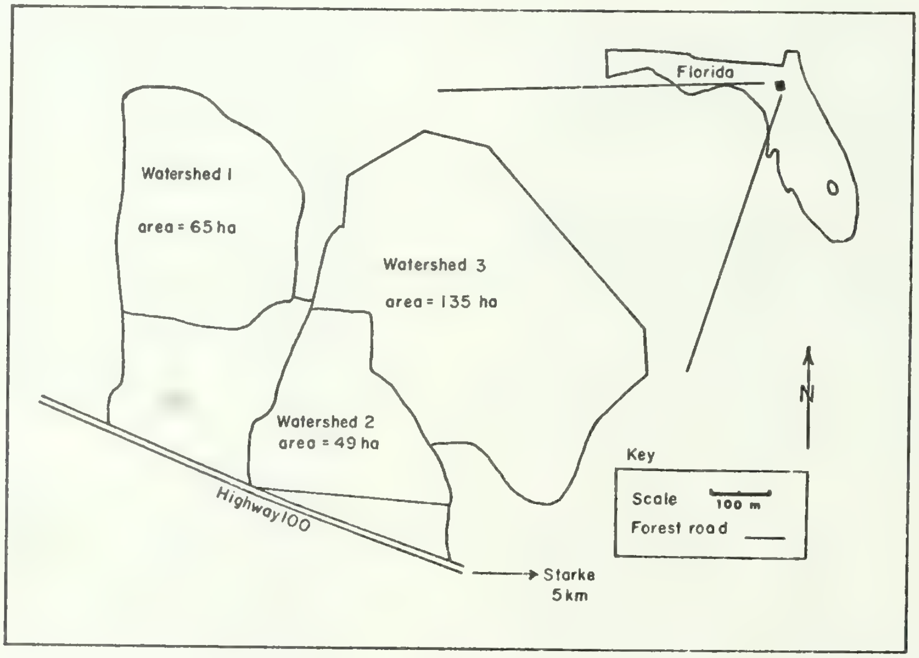

Figure 1.-Map showing location of experimental flatwoods watersheds, Bradford County, Florida.

The minimum treatment site (Watershed 1) retained a substantial amount of understory in the clearcuts. The clearcuts of the more intensively managed area (Watershed 2) were completely devoid of vegetation, except for slash that was pushed into windrows at approximately 50 m intervals after the site was burned.

Methods

Eight transects of lengths varying from 270 to 932 m were established at least 200 m apart in the three watersheds. Approximately 45% of the transect intersected pine and 55% intersected cypress/bay habitats in Watershed 1, 62% intersected pine and 38% intersected cypress/bay habitats in Watershed 2, and 80% intersected pine and 20% intersected cypress/bay habitats in Watershed 3 (the Control).

The transects were traversed 6 to 15 times per season, with the exception of the Autumn of 1978, when Watersheds 1 and 2 were harvested. Data were collected between sunrise and 1200 EST on days with favorable environmental conditions (Sheilds 1979). The order in which the transects were traversed was rotated so that each area would be monitored as often as possible in the early morning hours when birds were most active (Robbins 1978). Seasons were designated as winter (December through February), spring (March through May), summer (June through August), and autumn (September through November). For the purposes of this paper, birds present during the spring and summer constituted the breeding community, whereas those present in the autumn and winter comprised the wintering community.

Birds seen or heard within 10 m of the transect line were recorded and from these data, density (birds/km^2) and diversity were determined. In addition, birds seen or heard from 10 to 100 m from the transect line were recorded to augment the species composition list.

Analyses of variance using a split-plot model (Steel and Torrie 1960) were used to determine differences in density of birds by season and watershed, before and after harvesting. Bird species diversity was determined using the Shannon-Wiener Index (Shannon and Weaver 1949). The index is defined as:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

where: H' = diversity index
s = total number of species
i = species number
p_i = proportion of the community that belongs to the i^{th} species

Minimum diversity ($H' = 0$) is attained when only one species is present. Maximum diversity ($H' = \ln s$) is achieved when all individuals are equally apportioned among the species present.

Table 1.--Forest Treatments applied to flatwoods Watersheds 1 and 2, Bradford County, Florida.

Date	Forestry Practices Applied	
	Watershed 1 (Min. Treatment Area)	Watershed 2 (Max. Treatment Area)
Nov-Dec 1978	Harvest (Shortwood)	Harvest (Shortwood)
Jan-Feb 1979	--	Lightwood Stump Removal
April 1979	Chop	--
May 1979	--	Burn
June 1979	--	Windrow (KG-Blade)
August 1979	Chop	Harrow
Sept-Oct 1979	Bed	Bed
November 1979	Plant (Mechanical)	Plant (Mechanical)

Data collected on the watersheds from June 1977 to August 1978 were considered to be baseline information. When referring to trends in the treatment watersheds after harvest, it should be noted that the number of species, density, and diversity were determined from data collected in intact cypress/bay habitats as well as cleared areas. Most tracts that are harvested in the North Florida flatwoods contain cypress/bay areas that are left intact. Homogeneous clearcuts probably would not exhibit similar population trends.

Results and Discussion

Overall density of birds in the less intensively managed tract (Watershed 1) increased in all seasons after harvest (Figure 2). This tract retained substantial cypress/bay habitat after the harvest. The increase in avian density was apparently due to retention of flatwoods species in the intact cypress/bay habitats and the addition of species attracted to the clearings. Also, edges created between cypress/bay areas and clearcuts may have contributed to higher bird densities on Watershed 1. McElveen (1978) found breeding bird densities were greater in edges between cypress/bay areas and clearcuts than in cypress/bay and pine ecotones in North Florida flatwoods.

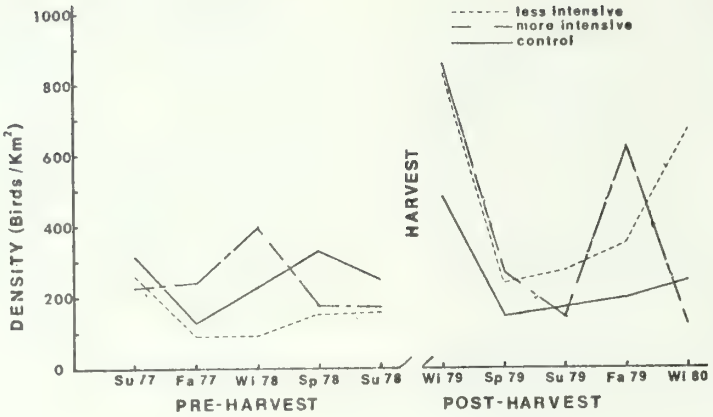

Figure 2.--Seasonal variation in density (birds/km^2) on the 3 study areas before and after harvest in Bradford Forest, Bradford County, Florida, June 1977 - February 1980.

No obvious trends existed in overall avian density for Watershed 2 (Figure 2) or for bird species diversity (Figure 3) and number of species (Figure 4) for both Watersheds 1 and 2.

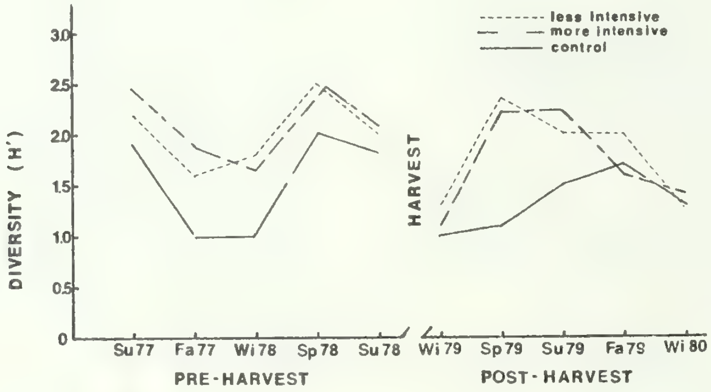

Figure 3.--Seasonal variation in diversity (H') on the 3 study areas before and after harvest in Bradford Forest, Bradford County, Florida, June 1977 - February 1980.

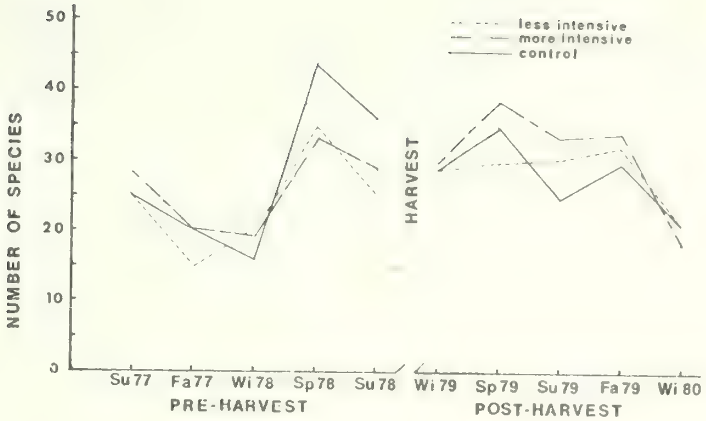

Figure 4.--Seasonal variation in number of species on the 3 study areas before and after harvest in Bradford Forest, Bradford County, Florida, June 1977 - February 1980.

Analyses of variance showed no significant differences in pre-harvest data within or between seasons. After harvest, the winter of 1979 had significantly greater avian densities than the other seasons ($\underline{P} < 0.05$, LS Means Test). However, bird density in the treatment areas did not differ significantly from the control in the winter of 1979. The increase in densities was apparently due to normal population fluctuations rather than the silvicultural treatments.

Overall, the control area had a high number of species, density, and diversity in the spring and summer just prior to harvest. Avian composition may have been affected by the construction of a powerline corridor through the site in the autumn of 1977 and the winter of 1978. Borrow pits dug along the side of the corridor in the winter of 1978 were periodically inundated with water, attracting several species of wading birds to the site in the spring and summer of 1978 (Table 2). As vegetation regenerated along the corridor, it became less attractive to these species, resulting in a lower number of species, density, and diversity the following spring and summer. The powerline corridor also bisected Watershed 2, but we were unable to segregate responses of birds to powerline construction from those associated with on-site silvicultural practices.

As understory vegetation began to regenerate, several bird species began to utilize the cleared areas in both Watersheds 1 and 2. These species included the American kestrel (Falco sparverius), killdeer (Charadrius vociferus), common snipe (Capella gallinago), ground dove (Columbina passerina), red-headed woodpecker (Melanerpes erythrocephalus), eastern phoebe (Sayornis phoebe), loggerhead shrike (Lanius ludovicianus), eastern meadowlark (Sturnella magna), and red-winged blackbird(Agelaius phoeniceus).

The creation of windrows apparently further attracted avian species to Watershed 2. House wrens (Troglodytes aeden), mockingbirds (Mimus polyglottos), and eastern bluebirds (Sialia sialis) were commonly seen utilizing the windrows.

Densities of several indigenous flatwoods avian species increased on the harvested tracts. Large flocks of American robins (Turdus migratorius) and mourning doves (Zenaida macroura) were observed feeding in the cleared areas of Watershed 2. The reduction of ground vegetation and litter in this area probably exposed some forage items that otherwise would not have been available (Wood and Niles 1978). Thick stands of grass that regenerated along the southern edge of Watershed 2 attracted white-throated (Zonotrichia albicollis) and swamp sparrows (Melospiza georgiana), resulting in increased densities of these birds in this area (Table 2). Finally, the interface between the clearcuts and cypress/bay habitats in Watershed 1 attracted large flocks of yellow-rumped warblers (Dendroica coronata), palm warblers (Dendroica palmarum), and red-winged blackbirds, increasing the density of these species in Watershed 1 (Table 2).

Most of the species that made use of the clearcuts were open land species previously unrecorded in the area, or indigenous flatwoods birds that overwintered in the area. Very few birds were observed in the clearcuts during the breeding season. Eastern meadowlarks were heard singing in the clearcuts of Watershed 1 in the summer of 1979. Bachman's sparrows were heard

Table 2.--Density (birds/km^2) of 89 bird species recorded in Watershed 1 (less intensive practices), Watershed 2 (more intensive practices), and Watershed 3 (nondisturbed) in Bradford County, Florida, June 1977 - February 1980.

Species[1]	Seasonal Status[2]	PRE-HARVEST												POST-HARVEST																	
		Summer 77			Autumn 77			Winter 78			Spring 78			Summer 78			Winter 79			Spring 79			Summer 79			Autumn 79			Winter 80		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Wood Duck (*Aix sponsa*)	R											X[3]												X							
Common Egret (*Casmerodius albus*)	R							X								X					X						X				
Cattle Egret (*Bubulcus ibis*)															X	X															
Little Blue Heron (*Florida caerulea*)	R												X		X	X		X	X		4	X		8	X						
Green Heron (*Butorides virescens*)	R										6			X		5															
Black Vulture (*Coragyps atratus*)	R	X									X		X	X						6											
Turkey Vulture (*Cathartes aura*)	R		X								X		X						X											X	
Cooper's Hawk (*Accipiter cooperii*)	R												X																		
Sharp-Shinned Hawk (*Accipiter striatus*)	W										5																				
Red-Tailed Hawk (*Buteo jamaicensis*)	R												X																		
Red-Shouldered Hawk (*Buteo lineatus*)	R							X			X		22	X							X		X	X			X				X
American Kestrel (*Falco sparverius*)	R																									9	X		X		
Bobwhite (*Colinus virginianus*)	R	X	6	13		55			/8	150	13	11	145	16	10	X		116				3	22	17	X						
Killdeer (*Charadrius vociferus*)	R																										X				
Spotted Sandpiper (*Actitis macularia*)	T											X	26		X																
Common Snipe (*Capella gallinago*)	W										X															X					
Mourning Dove (*Zenaida macroura*)	R	X	10	X		X					X		13	11	41	X		X	X	X	7	X	X	4	X	X	78	X	X	X	X
Ground Dove (*Columbina passerina*)	R																				X			8							
Yellow-Billed Cuckoo (*Coccyzus americanus*)	S		X								X	6			X								X	X							
Great Horned Owl (*Bubo virginianus*)	R			X																		X									
Screech Owl (*Otus asio*)	R																			X											
Chuck-Will's Widow (*Caprimulgus carolinensis*)	S												93			17						13									
Common Nighthawk (*Chordeiles minor*)	S												X		8	X							X	X							
Ruby-Throated Hummingbird (*Archilochus colubris*)	S												X											12							
Belted Kingfisher (*Megaceryle alcyon*)	W					X										5				X	X						X				
Common Flicker (*Colaptes auratus*)	R	X	6	X								X				37	X	X	X	X			7			X	16	X		22	X
Pileated Woodpecker (*Dryocopus pileatus*)	R	8	6	X						X	X	6	X	X		X				X	X	X	14	X	X	9		X	X		
Red-Bellied Woodpecker (*Melanerpes carolinus*)	R	21	12	X	19	X	X	6	X	X	X	16	X	23	13	16	20	8	11	12	18	X	7	4	8	4	22	X	X	22	X
Red-Headed Woodpecker (*Melanerpes erythrocephalus*)	R																				X		7								
Yellow-Bellied Sapsucker (*Sphrapicus varius*)	W						X	6		X							X	X	3		X	X					11	X			X
Hairy Woodpecker (*Picoides villosus*)	R		12			X						7																			
Downy Woodpecker (*Picoides pubescens*)	R	X	X	10		X			10		X		X	5	X	20		X	X		3		13	8	7	9	22	3			
Great Crested Flycatcher (*Myiarchus crinitus*)	S	14	12	59							5	9	14	6	19	11				6	21	8	3	25	7						
Eastern Phoebe (*Sayornis phoebe*)	W																13	X								9	X			22	
Eastern Wood Pewee (*Contopus virens*)	S											X																			
Tree Swallow (*Iridoprocne bicolor*)	W																									X	X				
Blue Jay (*Cyanocitta cristata*)	R	4	19	17		X	X				X	20	14	5	X	X	X	X		3	22	14	X	X	10	X	5	X	X	X	
Common Crow (*Corvus brachyrhynchos*)	R		X				X		X			X				X	X	X	8			X		X	X	X	10	X			X

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[1] Scientific names from Check-list of North American Birds (American Ornithologists' Union 1957) and its supplements (American Ornithologists' Union 1973, 1976).

[2] Seasonal status determined from a local check-list (Austin 1975), R = resident, W = winter resident, S = summer resident, T = transient.

[3] X denotes bird was present on the site, but was not observed on the transects being monitored for density estimates.

Table 2, cont'd.

		PRE-HARVEST															POST-HARVEST														
	Seasonal	Summer 77			Autumn 77			Winter 78			Spring 78			Summer 78			Winter 79			Spring 79			Summer 79			Autumn 79			Winter 80		
Species[1/]	Status[2/]	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Fish Crow (*Corvus ossifragus*)	R		X								X		X							X	7	X	X	8							
Carolina Chickadee (*Parus carolinensis*)	R	5	12	33	X	22	39	30	X		X	X	13	X	14	31	7	4	X	12	X	X	7		4		11	10	X		X
Tufted Titmouse (*Parus bicolor*)	R	X	12	43	X	21	19	X	16	49	5	7	27	6	8	74	X		17	X	4	3	X	X	5	X	X	14	X	X	X
Brown-headed Nuthatch (*Sitta pusilla*)	R	X	10	14	X		X	X			X	X	X	22	14	35	7	X	8	3	X	3	X	X	4	X		X			
House Wren (*Troglodytes aedon*)	W																X	8	X	X	14	6				X	6	X		X	X
Carolina Wren (*Thryothorus ludovicianus*)	R	36	39	46	30	16	30	29	28	20	9	7	24	59	33	29	32	12	4	16	29	17	52	33	22	28	11	19	19	34	23
Mockingbird (*Mimus polyglottos*)	R														X	5	7	X			7					22	39		18	X	
Gray Catbird (*Dumetella carolinensis*)	W				10	X	X	16	X		15	6	14		X		46	8	X	54	X	X				52		7	29		30
Brown Thrasher (*Toxostoma rufum*)	R	4	12	9	X		20			X	5		X	5		37				X			22	X	X	5	X				
American Robin (*Turdus migratorius*)	W					52	X	12	173	140			X				373	587	251							22	145		153	11	127
Hermit Thrush (*Catharus guttata*)	W																	X													30
Swainson's Thrush (*Catharus ustulata*)	T					22		6																							
Eastern Bluebird (*Sialia sialis*)	R										X			X			X				X		7	4		90	10			X	
Blue-Gray Gnatcatcher (*Polioptila caerulea*)	R	23	14	23							9	15	20	6	X	X				9	19	3	10	8	10		22	10			
Ruby-Crowned Kinglet (*Regulus calendula*)	W							X	38	18	6	7	12				21	4	21	6	7	20				14	6	7	9	X	7
Cedar Waxwing (*Bombycilla cedrorum*)	W																X		X	96	X	41									
Loggerhead Shrike (*Lanius ludovicianus*)	R																							8		X	11				
Solitary Vireo (*Vireo solitarius*)	W				X	X		X		X			14						X			X							18		
White-Eyed Vireo (*Vireo griseus*)	R	6	6	24	29	44	20	12	X	73	6	13	26	6	7	X	X		X	13		10	14	X	14	9		17	9		X
Yellow-Throated Vireo (*Vireo flavifrons*)	S										X		X											X							
Red-Eyed Vireo (*Vireo olivaceus*)	S															X															
Black-and-White Warbler (*Mniotilta varia*)	W					X	20	6	8	11	12		X				7	X	79	X	7	X				10		10	X		X
Prothonotary Warbler (*Protonotaria citrea*)	S	17	X	X							5	X		11	X								7	8							
Northern Parula Warbler (*Parula americana*)	S	X	6	16	X		X				6	7	22	17	21	15				16	7	3	7	X	X			X			
Cape May Warbler (*Dendroica tigrina*)	T										X		X																		
Yellow-Rumped Warbler (*Dendroica coronata*)	W				X	X	19	X	105	130		20	67				337	192	153	X	100	10				X	235	27	214	11	
Black-Throated Blue Warbler (*Dendroica caerulescens*)	T																					X									
Yellow-Throated Warbler (*Dendroica dominica*)	S	17		X							X	X	X		X					X	7	X			X						
Blackpoll Warbler (*Dendroica striata*)	T											X																			
Pine Warbler (*Dendroica pinus*)	R	14	29	27	X	27	50	7	19	14	21	15	50	5	X	49	13	4	9	X	3	5	10	8	27	4	6	42			23
Prairie Warbler (*Dendroica discolor*)	T	4	10												7	17															
Palm Warbler (*Dendroica palmarum*)	W												14				7	X								104	21				
Ovenbird (*Seiurus aurocapillus*)	W											6																			
Common Yellowthroat (*Geothlypis trichas*)	R	50	30	21	15	22	28	16	26	19	24	30	14	11	28	45	14	X	9	9	X	19	66	4	28	23	22	24	9	22	62
American Redstart (*Setophaga ruticilla*)	T						X					7				15				12		X				5		13			
Eastern Meadowlark (*Sturnella magna*)	R																						X				X		X		
Red-Winged Blackbird (*Agelaius phoeniceus*)	R																				X						X		573		
Boat-tailed Grackle (*Quiscalus mexicanus*)	R												X																		
Common Grackle (*Quiscalus quiscula*)	R											X	11			X					15		74	8	X						
Summer Tanager (*Piranga rubra*)	S	X	X	X								X	X	X		X						X			7			20			
Cardinal (*Cardinalis cardinalis*)	R	10	35	8	10	11	41	6			19	6	12	6	X	74	13	X	17	6		27	11	X	7	5	22	X			13
Rose-Breasted Grosbeak (*Pheucticus ludovicianus*)	T																				7										
Indigo Bunting (*Passerina cyanea*)	S															X															
American Goldfinch (*Carduelis tristis*)	W												X															19			
Rufous-Sided Towhee (*Pipilo Erythrophthalmus*)	R	64	16	87	20	21	40	14	22	X	17	40	67	25	29	57	25	X	17	15	7	38	21	25	57	23		45	X	22	26
Bachman's Sparrow (*Aimophila aestivalis*)	R			X																	X		3								
Chipping Sparrow (*Spizella passerina*)	W																											18	X		
Field Sparrow (*Spizella pusilla*)	W							X	240																						
White-throated Sparrow (*Zonotrichia albicollis*)	W								29		13		14					8			21										X
Swamp Sparrow (*Melospiza georgiana*)	W											X					X	39	X					7		9	X	X		X	
Song Sparrow (*Melospiza melodia*)	W							10																						10	

1/ Scientific names from Check-list of North American Birds (American Ornithologists' Union 1957) and its supplements (American Ornithologists' Union 1973, 1976).

2/ Seasonal status determined from a local check-list (Austin 1975), R = resident, W = winter resident, S = summer resident, T = transient.

3/ X denotes bird was present on the site, but was not observed on the transects being monitored for density estimates.

singing in the clearcuts and along the cypress/bay/clearcut interface in both harvested tracts in the spring and summer of 1979. On occasion, Carolina wrens (Thryothorus ludovicianus) and rufous-sided towhees (Pipilo erythropthalmus) were observed singing in the windrows in Watershed 2. However, while most of the breeding indigenous flatwoods bird species still occurred in Watersheds 1 and 2 after harvest, they resided primarily in the intact cypress/bay habitats. Most of the bird species that breed in the flatwoods associate with the understory or are generalists that will breed in the canopy of more than one forest type. The brown-headed nuthatch (Sitta pusilla) and the pine warbler (Dendroica pinus) are the only two species specifically adapted to breed in the canopy of the southeastern flatwoods (Johnston and Odum 1956). Cavity nesters comprised 29 percent of the breeding species in the study area prior to harvest (Rowse 1980). Approximately half of the cavity nesting species in the area are primary (excavate their own cavity) cavity nesters. Since primary cavity nesters usually excavate their holes in dead trees, snags are an important feature of the forest to the indigenous cavity nester (Conner 1978). The most common breeding species of the flatwoods, Carolina wrens, common yellowthroats (Geothylpis trichas), and rufous-sided towhees, breed in the understory.

When avian species select a habitat type, they seek conditions that will best enable them to fulfill their needs for survival and reproduction including a certain type of landscape and terrain, an ample food source, and adequate nesting, singing, and drinking sites (Hilden 1965). It has been well documented that different species are attracted to certain features of the landscape and terrain unique to their needs (James 1971, Shugart and Patten 1972). Even though breeding species did not decrease on the treatment sites after harvest (Table 2), they occurred primarily in the intact cypress/bay habitats and made little use of the clearcut areas. Therefore, breeding indigenous flatwoods birds could only satisfy their habitat requirements in the intact cypress/bay areas of the harvested tracts.

There will always be trade-offs between managing an area for economic gains and managing it for wildlife habitat, but if it is in the interest of forest industry to manage an area to include a variety of resource values, the following recommendations are applicable:

1) Continue to maintain cypress/bay habitat in harvested tracts. These areas serve as a refuge for indigenous flatwoods avian species that could potentially repopulate adjacent plantation areas as they mature.

2) Leave snags standing wherever possible. These trees provide special habitat requirements for cavity nesting species, in addition to serving as perch sites for hawks and owls, and as food sources for many types of passerine birds.

3) Allow some development of understory vegetation in plantations. Many of the indigenous avifauna of the flatwoods use the understory for breeding and feeding.

4) Push slash into windrows. Windrows add heterogeneity to clearcuts and provide food and cover for some of the flatwoods species as well as open land species that may be attracted to the site.

LITERATURE CITED

erican Ornithologists' Union.
1957. Check-list of North American birds. 5th ed. Lord Baltimore Press, Baltimore, Maryland. 691pp.

_____. 1973. Thirty-second supplement to the American Ornithologists' Union Check-list of North American birds. Auk 90:411-419.

_____. 1976. Thirty-third supplement to the American Ornithologists' Union Check-list of North American birds. Auk 93:875-879.

stin, O. L.
1975. Birds of the Gainesville region, Florida: a check-list. Florida State Museum, Gainesville. 23pp.

nner, R. N.
1978. Snag management for cavity nesting birds. Pages 120-218 in Proc. workshop on management of southern forests for nongame birds. U. S. Dept. Agric. For. Serv. Gen. Tech. Rep. SE-14, Atlanta, Georgia.

_____.
1979. Effects of pine-oak clearcutting on winter and breeding birds in southwestern Virginia. Wilson Bull. 91:301-316.

ckson, J. G., and C. A. Segelquist.
1977. Winter bird populations in pine and pine-hardwood stands in east Texas. Proc. Southeastern Assoc. Fish Wildl. Agencies 31:134-137.

lden, O.
1965. Habitat selection by birds. Ann. Zool. Fenn. 2:53-57.

mes, F. C.
1971. Ordinations of habitat requirements among birds. Wilson Bull. 83:215-236.

hnston, D. W., and E. P. Odum.
1956. Breeding bird populations in relation to plant succession in the Piedmont of Georgia. Ecology 37:50-62.

Arthur, L. B., and R. C. Whitmore.
1979. Passerine community composition and diversity in man altered environments. West Virginia For. Notes 7:1-12.

Elveen, J. D.
1978. The effect of different edge types and habitat sizes on the distribution of breeding birds in North Florida. Unpubl. M. S. Thesis. Univ. of Florida, Gainesville. 58pp.

ble, R. E., and R. B. Hamilton.
1975. Bird populations in even-aged loblolly pine forests of southeastern Louisiana. Proc. Southeastern Assoc. Game and Fish Commissioners 28:659-667.

Perkins, C. J.
1973. Effects of clearcutting and site-preparation on the vegetation and wildlife in the flatwoods of Kemper County, Mississippi. Unpubl. Ph.D. dissert., Mississippi State University, Starkeville. 236pp.

Riekerk, H. F., B. F. Swindel, and J. A. Replogle.
1980. Initial hydrologic effects of forestry practices in Florida flatwoods watersheds. IMPAC Report 5(4). Univ. of Florida, Gainesville. 23pp.

Robbins, C. S.
1978. Census techniques for birds. Pages 142-163 in Proc. workshop on management of southern forests for nongame birds. U. S. Dept. Agric. For. Serv. Gen. Tech. Rep. SE-14, Atlanta, Georgia.

Rowse, L. A.
1980. Avian community composition of a North Florida flatwoods. Unpubl. M. S. Thesis, Univ. of Florida, Gainesville. 69pp.

Shannon, C. E., and W. Weaver.
1949. The mathematical theory of communication. Univ. of Illinois Press, Urbana. 117pp.

Shields, W. M.
1979. Avian census techniques: an analytical review. Pages 23-51 in J. G. Dickson, R. N. Conner, R. R. Fleet, J. R. Kroll, and J. A. Jackson, eds. The role of insectivorous birds in forest ecosystems. Academic Press, Inc., New York, New York.

Shugart, H. H., Jr., and B. C. Patten.
1972. Niche qualification and the concept of niche pattern. Pages 283-325 in B. C. Patten, ed. Systems analysis and simulation ecology. Academic Press, Inc., New York, New York.

Steel, R. G. D., and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Company, Inc., New York, Toronto, and London. 481pp.

U. S. Department of Agriculture.
1978. Forest statistics of the United States. U. S. Dept. Agric. For.Serv. Rep.

Wood, G. W., and L. J. Niles.
1978. Effects of management practices on nongame bird habitat in longleaf-slash pine forests. Pages 40-49 in Proc. workshop on management of southern forests for nongame birds. U. S. Dept. Agric. For. Serv. Gen. Tech. Rep. SE-14, Atlanta, Georgia.

RE-ESTABLISHING YELLOW PINE HABITAT FOR THE RED COCKADED WOODPECKER ON THE CUMBERLAND PLATEAU[1]

J. Daniel Thomas and Edward Buckner[2]

Abstract.--Developing inexpensive silvicultural systems for increasing the pine component of forests on the Cumberland Plateau is essential for maintaining a population of red cockaded woodpeckers in that area. Site preparation and hardwood control techniques considered feasible and acceptable on the Catoosa Wildlife Management Area were tested; these included: (1) burning, (2) fire plowing, (3) drum chopping, and (4) a velpar treatment. Both direct seeding and planting were tested for establishing shortleaf pine, and deer exclosures were constructed to determine the influence of deer browsing on stand composition.

First year survival was best in the fireplowed rows for both direct seeding and planted seedlings. However, total height was greatest for planted seedlings in the drum-chopped area. Burning had no significant effect.

The effectiveness of the hardwood control treatments was evaluated by recording for each planting "spot" the likelihood that an established pine seedling (whether present or not) would outgrow hardwood competition. Both fire plowing and drum chopping significantly reduced hardwood competition.

INTRODUCTION

Once common in the southeast, the red cockaded woodpecker (Picoides borealis) is currently listed as an endangered species, primarily due to loss of suitable habitat (Jackson et al, 1979).

A remnant population (2-3 pairs) still remains on a marginal habitat on the Catoosa Wildlife Management Area (CWMA) on the Cumberland Plateau in Tennessee. This is the only population on public lands in the State where management goals will allow restoration of the habitat. The single most important habitat requirement is a mature or decadent stand of yellow pine for nesting.

Natural succession in this region is to hardwoods and the few remaining old pine stands are being replaced with hardwoods. Silvicultural systems used on the CWMA are not intensive and generally result in release of hardwood competition, further reducing the pine acreage.

The intensive site preparation methods used by industry are neither economically feasible nor compatible with management objectives for the area. Developing inexpensive silvicultural systems for favoring pine is essential for maintaining a population of red cockaded woodpeckers on the CWMA (the largest - 80,000 acres - wildlife management unit in Tennessee).

Attempts over the last several years to manipulate habitats to favor the red cockaded woodpecker on the CWMA have been unsuccessful. Historical accounts indicate that fire played a key role in the establishment of the remnant pine stands that provide their present habitat.

This study was designed to test economically feasible silvicultural systems for increasing the pine component on the CWMA.

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[1] Funded thru the endangered species fund by U. S. Fish and Wildlife Service and the Tennessee Wildlife Resources Agency.

[2] Graduate Research Assistant and Associate Professor, respectively, Department of Forestry, Wildlife and Fisheries, University of Tennessee, Knoxville, TN 37901.

METHODS

Study Area. The study locations were on a road ridge in an area designated for management s red cockaded woodpecker habitat. Two study lots (900' x 900' = 18.4 acres each) were stablished where soils and forest cover appeared niform.

To simulate conditions following logging (an ctivity that will usually precede any effort o convert to pine), hardwoods larger than 3" iameter were removed and/or poisoned (a stipulaion in all logging contracts on the CWMA).

The original forest cover was characterized hrough four sample plots in an adjacent area hat was not disturbed. Trees greater than 1 inches d.b.h. were tallied on 1/5 acre plots; oncentric plots of 1/20, 1/40, and 1/100-acres ere established on which, respectively, pulpwood 3 inches to 11 inches d.b.h.), saplings (6' tall o 3 inches d.b.h.), and regeneration (trees ess than 6 feet tall) were measured.

Treatments tested for establishing shortleaf ine (*Pinus echinata* Mill.) were:

A) Site preparation to control competing vegetation.

1. Burn types:

    a) spring burn
    b) summer burn
    c) both spring and summer burns
    d) control

2. Mechanical treatments:

    a) fire plowing
    b) drum chopping
    c) control

3. A velpar "gridball" application

B) Planting methods

1. direct seeding

2. planting seedlings

C) Deer exclosure (to determine the influence of deer browsing on the establishment and growth of shortleaf pine and on the unwanted hardwood competition.)

The large study plots were divided into four qual subplots for testing the burn and control reatments. Summer burning was done in July 1978 nd spring burning in March, 1979. One subplot in ach area was burned on both dates (Figure 1).

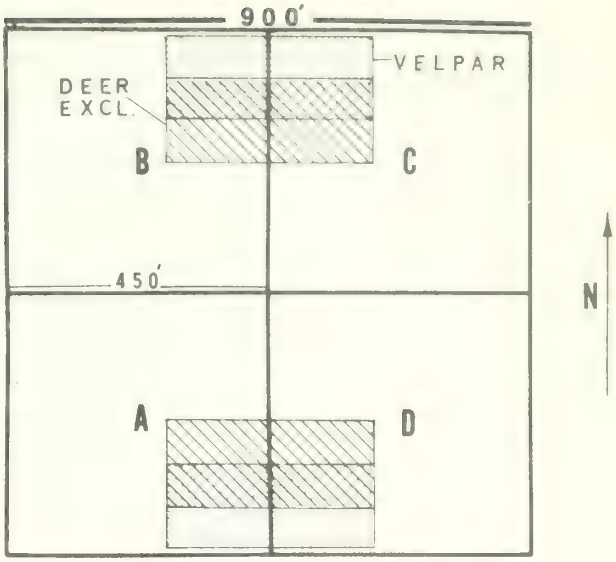

Figure 1. Arrangement of burn treatments, deer exclosures, and velpar treatments.

Two methods of mechanical site preparation were tested against a control in each of the 4 main treatment plots. A split block arrangement was used in which fire plow and drum chopper rows (15 feet wide) ran in a north-south direction the entire length of the study plots. These mechanical treatment sub-units consisted of the random assignment of the 3 treatments (applied to the 15 foot strips) to the 45-foot wide mechanical treatment unit (See Figure 1). Soil samples (40 at each location) were taken, half from the bottom of the fireplow trench and the other half from undisturbed soil.

Regeneration methods were tested by alternating between direct seeding in one mechanically prepared unit to planting 1-0 seedlings in the next unit. Seedlings were from the Tennessee Division of Forestry nursery in Pinson, Tennessee; the seeds used in direct seeding were obtained from the Division of Forestry, Fisheries and Wildlife, Tennessee Valley Authority, and were from southeastern Kentucky (source 64, lot 2). The germination percentage for these seeds was approximately 80 percent.

Plantings were at 7 foot intervals in rows that were 15 feet apart; planting rows were centered in the mechanically prepared strip. Seeds were treated with bird and rodent repellent prior to direct seeding. Plastic flagging was used to mark the direct seeding locations, which were scarified prior to placing 1-3 seeds at each point of a triangular arrangement having approximately 1-foot sides.

Following planting, Velpar "gridballs" were placed on a 6' x 6' grid. Approximately 1.25 acres were treated at each location to give equal portions of all treatments (Figure 1). The size of both the deer exclosures (375 ft. x 145 ft) and the Velpar treatments were dictated by the requirement that at least 2 replications of each mechanical treatment and planting method be included in each of the burn types.

Construction delays resulted in deer exclosures not being operational the first growing season, therefore negating any further inferences at this time.

Survival, height, and hardwood encroachment on planting positions were measured in the spring of 1980, one year after planting, residual hardwood competition at each planting position was measured on a scale of increasing competition where 1 represented no competition to 5 representing complete over topping that will likely result in the death of an established pine seedling. These measurements were made after hardwoods were in full leaf to accurately judge the degree of competition.

RESULTS AND DISCUSSION

Differences between the two study areas that became apparent during the inventory include: (1) the south area had more large residual pines (not removed since conversion was to pine), (2) there was a dense ground cover of grass on the south area.

Dispite greater competition from large pines and grass, hardwood competition was greater in the south area (3.3) than in the north (2.9) (Table 1). More seedlings were established from direct seeding on the north area, probably due to less grass and hardwood competition. Survival of planted seedlings was approximately equal for the two areas, as was their total height.

Treatments. The three burn types had no significant effect on any of the parameters measured.

Among mechanical treatments, planting in fireplow trenches resulted in much higher survival, both for tree planting and direct seeding (70 and 74 percent respectively, compared to 50 and 27 percent for the other mechanical treatment). These greatly improved survival and establishment percentages for planted seedlings and direct seeding can probably be attributed to decreased root competition and greater available soil moisture in the fireplow trench; exposing mineral soil provided a further establishment advantage for direct seeding.

Survival and establishment were not significantly improved by drum chopping; however, the height of planted seedlings was 9 percent greater ($P \geq 0.05$) (Table 1). This gain over control likely resulted from reduced hardwood competition. The absence of a height-growth response to reduced competition in the fireplow rows can be attributed to poor physical and chemical soil properties (P and K were significantly lower - $P \geq 0.05$ - in fireplow rows).

Table 1. Least squares means for treatment effects on the two areas. An asterisk indicates mean(s) significantly different at the 0.05 level.

AREAS AND TREATMENTS	Hardwood Competition[1]	Total Height (Seedlings) inches	Survival (Seedlings) percent	Establishment (Seeds) percent
AREA				
North	2.9	13.9	55	44
South	3.3*	14.2*	57	38*
MECHANICAL TREATMENT				
None	3.7*	13.7	49	21
Fireplow	2.8	13.7	70*	74*
Drum Chop	2.9	14.9*	50	27
VELPAR GRIDBALLS				
Untreated	3.3	13.6	56	38
Treated	2.9*	14.5*	57	43*

In velpar-treated plots: (1) hardwood competition was reduced, (2) the height growth of planted seedlings was greater, and (3) establishment from direct seeding was greater ($P \geq 0.05$ for all). The 12 percent reduction in residual hardwood competition probably accounts for the 7 percent increase in the height of planted seedlings and a 13 percent increase in establishment from direct seeding, suggesting that velpar had a positive effect in establishing pine.

SUMMARY AND CONCLUSIONS

These preliminary results indicate that the pine component of forest stands on the CWMA can be increased using equipment and systems that are feasible under guidelines established by the Tennessee Wildlife Resources Agency[3].

While burning is convenient and inexpensive and is commonly used on the CWMA, it was not effective as used in this study. Williamson (1964) found that controlled burning of oak-pine stands on the Cumberland Plateau decreased the height of the hardwood understory but increased the number of stems making it almost impossible to regenerate shortleaf pine. However, since burning conditions on both dates used in this study were less than favorable, further investigation is suggested.

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[3] Personal communication.

Although mechanical treatments are more expensive than burning, those tested appear to be more effective for establishing pine on the Cumberland Plateau. Planting in fireplow trenches resulted in over 70 percent establishment with both tree planting and direct seeding, while establishment in other treatments was 50 percent or less. This establishment gain offsets the small height growth advantage of planted seedlings in the drum chopped plots, a condition that may change when roots grow into the undisturbed soil outside the zone affected by fireplowing. Disadvantages of parallel fireplow rows 15 feet apart is the soil-site disturbance and reduced aesthetic quality for most users of the area.

Fireplowing, drum chopping and velpar apparently reduced hardwood competition for established pine seedlings and drum chopping and velpar appeared to improve growth.

These results suggest that mechanical treatments sufficient to expose mineral soil are needed to adequately establish pine but the best growth will result if soil disturbance is minimal. Hardwood competition indices below 3.0 are probably needed to get established pine into the overstory; both chemical and mechanical site preparation methods accomplished this (Table 1).

Further tests should be made to identify site preparation techniques less drastic than fireplowing that will enable the establishment of pine and reduce hardwood competition.

LITERATURE CITED

Jackson, Jerome A., Michael R. Lennartz, and Robert G. Hooper.
1979. Tree age and cavity initiation by red cockaded woodpeckers. Journal of Forestry 77, No. 2. p. 102-103.

Williamson, Malcolm J.
1964. Burning does not control young hardwoods on shortleaf pine sites on the Cumberland Plateau. USDA Forest Service. Research Note CS-19. 4 p.

FOREST STAND SIMULATION MODEL FOR THE CATOOSA WILDLIFE MANAGEMENT AREA (FORCAT)[1]

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Abstract.--The assumptions and implementation of a forest stand model are presented. The model simulates the dynamics of up to 700 individual trees on a small circular plot. Preliminary results from the application of the model to an upland forest are presented.

INTRODUCTION

Forestry and wildlife managers are often confronted with conflicting demands for resource utilization. The conflicts may be temporal, spatial, or some combination of both. Immediate and intensive management versus long term and sustained yield harvesting of timber may result in a temporal conflict. Concurrent use of an area for wildlife management and timber harvest may create a spatial conflict. As the temporal and spatial scales increase, the formulation of satisfactory management strategies becomes increasingly difficult. Simulation models are one possible aid to decision makers. Models can assist the resource manager in assessing the impact of different management strategies in such areas as resource harvest and regeneration. The development of a forest stand simulation model for the Catoosa Wildlife Management Area (FORCAT) is described. One intended use of this model will be to investigate the interrelationship of deer browsing and forest stand development following cutting.

APPROACH

Shugart and West (1980) have categorized forest simulation models into three groups: individual tree models, gap models, and whole stand models. Individual tree models consider the growth of single trees. Such models are often used to simulate development of managed, commercia forests. Gap models simulate individual trees on a small spatial scale. Models of this type are generally used to investigate ecological successio Whole stand models consider the dynamics of a large forest or stand. Generally, these models do not consider the dynamics of individual trees.

The model described here is patterned after the gap models of Shugart and West (1977) and Botkin, et al. (1972). These models consider the dynamics of up to 700 trees on a small circular plot. The models utilize the silvicultural characteristics of each species on the plot to control the growth and development of individual trees. Monthly temperature and precipitation on the plot are used as the forcing environmental factors. The models assume that many of the factors influencing plot development are stochast in both frequency and magnitude. Consequently, these models must be run a number of times and the results averaged.

A gap model was chosen for three major reaso First, the size of the openings created by the proposed tree harvesting strategy on Catoosa is fairly small. A model which was capable of considering the regeneration dynamics of individual trees following harvest was considered important. Secondly, the impact of deer browsing on a tree is generally a function of the tree height. The taller a tree is, the less severe is the impact of deer browsing. The gap model of Shugart and West (1977) generate the height and foliage rofile of each individual on the simulated plot. his information can serve as input to a deer opulation model such as ONEPOP[5]. Lastly, the ong term consequences of deer browsing on forest evelopment can be investigated with gap models.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, GA, November 6-7,1980.

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The interface between the gap model and a eer population model is not discussed in this aper. Our first concern was to develop a model apable of simulating the long term dynamics of a orest on Catoosa. The impact of herbivory is urrently modeled by classifying each tree species s either preferred or non-preferred food. If a pecies is a preferred food for wildlife, the eeding and sprouting rates for that species are educed. Eventually, we hope to create more re- ined palatability indices for the tree species. hese indices along with the amount of vegetation f each species on the plot will be input to a eer population model which will allow more detailed imulation of the impact of herbivores.

DESCRIPTION OF THE FORCAT MODEL

FORCAT simulates the growth of each tree on 1/12 ha circular plot. Tree growth is modeled s a function of present tree size, climate, hading, and crowding from other trees. As in ORET (Shugart and West, 1977), tree growth under ptimal conditions is calculated by

$$\frac{Dv(t)}{dt} = \frac{d(D(t)^2H(t))}{dt} = (R)(LA(t))\frac{(1-D(t)H(t))}{D_{max}H_{max}}$$

here V(t), D(t), H(t), and LA(t) are the volume, iameter at breast height, height and leaf area, espectively, of a tree at time t. R, D_{max}, and $_{max}$ are the species specific growth rate, maximum iameter, and maximum height, respectively. This quation considers the tree to be a cylinder with he change in tree volume proportional to the mount of surface area available for photosynthesis ultiplied by a maintenance factor for the biomass resent (Botkin, et al., 1972).

Tree height, H(t), is assumed to be a quadratic unction of diameter at breast height, D(t) (Ker nd Smith, 1955)

$$H(t) = 137 + b_2D(t) - b_3D(t)^2$$

$_2$ and b_3 are species specific parameters and are alculated by assuming that $H(t) = H_{max}$ and $dH(t)/$ $D(t) = 0$ when $D(t) = D_{max}$. Maximum recorded height nd diameter at breast height for each species are sed as values for H_{max} and D_{max}.

Leaf area, LA(t), is calculated from the mpirical relationship (Sollins et al., 1973)

$$LA(t) = (0.1193)(D(t))^{2.939}$$

FORCAT decreases the optimum growth of a tree by factors to reflect the impact of shading, climate, competition, and herbivory. Available light for a given tree is modeled as an inverse exponential function of the leaf area above the tree. Two different equations, one for shade tolerant species and one for shade intolerant species, are used to relate available light to a photosynthetic rate factor, r(AL). The value of r(AL) can range from 0 representing poor light conditions to 1 which represents optimal light. The optimal growth equation is multiplied by r(AL) to incorporate the effects of shading tree growth.

Climatic influences on tree growth are of two types: temperature effects and moisture effects. The model assumes that each species has an optimal temperature for photosynthesis and that net photosynthesis decreases symmetrically as temperatures vary from this optimum. Growing degree days above a 42° F base for the site is used to calculate a temperature factor, T(DEGD), as follows

$$T(DEGD) = \frac{4(DEGD - DMIN)\ (DMAX - DEGD)}{(DMAX - DMIN)^2}$$

This function is a parabola with a maximum value of 1 at (DMAX + DMIN)/2 and a minimum value of 0 at DMIN and DMAX. The parameters DMAX and DMIN are species specific values taken to be the extremes of growing degree-days, DEGD, within the species range. The optimal growth equation is multiplied by T(DEGD) to incorporate the effect of temperature.

Decrease in tree growth as a result of moisture stress is modeled as the ratio between a species specific drought tolerance and the number of dry days on the site. Site dry days (DD) is defined as the number of days during the growing season on which the soil water was below wilting point. The field capacity and wilting point are site specific parameters. The model calculates monthly precipitation based on monthly means and variances for the site. Evapotranspiration based on the Thronthwaite equation is used to model loss of soil water. The species-specific drought tolerances are based on the extremes of moisture conditions within the species' range.

The final growth reducing effect considered in the model is related to increased biomass on the stand. This factor is calculated as

$$S(BAR) = 1 - \frac{BAR}{SOILQ}$$

where BAR is the total biomass on the plot and SOILQ is the maximum biomass recorded for forests in the area. This factor limits tree growth due to root competition.

FORCAT treats individual tree death as a stochastic process. The model assumes that only one percent of all seedlings of a species survive to reach the maximum age of that species. Trees which add less than 1 mm in diameter growth per year have an increased mortality rate.

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[5] Roelle, James E., and John M. Bartholow. 77. University of Colorado, Fort Collins, CO.

Two forms of regeneration are considered in the model: seedling establishment and sprouting. For each year of the simulation, the model determines which species are eligible to establish seedlings. Eligibility is based on the compatibility between the current plot conditions and the species' ecological requirements for successful seedling establishment. From the set of eligible species the model randomly chooses from one to three species. A random number of seedlings is added to the plot for each of the species selected.

Trees which have died during the previous year are checked to determine if they are eligible to sprout. Eligibility is based on the sprouting tendency of the species and a proper diameter of the dead tree. From the list of eligible trees, one tree is randomly selected and a random number of sprouts is added to the plot.

RESULTS AND DISCUSSION

The FORCAT model is still under development. The first version of FORCAT contained all the functions and factors discussed above except for the soil moisture growth reduction factor. This version of the model generated forest stands dominated by large tulip poplar (*Liriodendron tulipifera*).

The second version of FORCAT included the soil moisture growth reduction factor. The results of this version showed basal area dominance by the more xeric oaks. The model results were compared against a pre-harvest forest inventory collected by J. A. Muncy[6] and presented elsewhere in this conference.

The field data was collected on a stand (Table 1) between 50 and 75 years old. There is fairly good agreement between model and field data where the oaks are considered as a single group. However, the species composition within the oaks differs in the model and field data.

Table 1.--Basal area percent composition of Catoosa field data and FORCAT model results at 50 and 75 years.

	Basal Area Percent Composition		
SPECIES	FIELD DATA	MODEL-- 50 YRS	MODEL-- 75 YRS
Red maple (*Acer rubrum*)	1	12	11
Sugar maple (*Acer saccharum*)		7	6
Pignut hickory (*Carya glabra*)	3		
Mockernut hickory (*Carya tomentosa*)	1		
Dogwood (*Cornus florida*)	1	1	
White ash (*Fraxinus americana*)		1	
Sourwood (*Oxydendrum arboreum*)	4		
Virginia pine (*Pinus virginiana*)	6		
Black cherry (*Prunus serotina*)		2	1
White oak (*Quercus alba*)	4	3	
Scarlet oak (*Quercus eoccinea*)	27	7	5
Southern red oak (*Quercus falcata*)	14		
Blackjack oak (*Quercus marilandica*)	1		
Post oak (*Quercus stellata*)	28		
Black oak (*Quercus velutina*)	11	60	76
Sassafras (*Sassafras albidum*)		4	1

Modeling is an iterative learning process. Models are run and the results are compared against actual data and experience. If model results and data do not match, it is an indication that certain critical factors may be missing from the model. Such is the case with the current version of FORCAT.

The forests of the Cumberland Plateau have been subjected to a long history of man induced disturbances such as fire and logging. The next step is to include these disturbances as part of the model. It is, however, somewhat encouraging that the version of FORCAT described in this paper generates results which are not too dissimilar from the forests found on Catoosa. With the inclusion of fire, logging, and a more detailed browsing model we are hopeful that the model will generate even more realistic results.

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[6] Muncy, J. A., and E. Buckner. 1980. Stand development following clearcutting on the Cumberland Plateau in East Tennessee. Southern Silvicultural Research Conference.

LITERATURE CITED

Botkin, Daniel B., J. F. Janik, and J. R. Wallis. 1972. Some ecological consequences of a computer model of forest growth. J. Ecol. 60: 849-872.

Ker, J. W., and J. H. G. Smith. 1955. Advantages of the parabolic expression of height-diameter relationships. Forestry Chron. 31: 235-246.

Shugart, Herman H., Jr., and Darrell C. West. 1980. Forest succession models. Bioscience 30: 308-313.

Shugart, Herman H., Jr., and Darrell C. West 1977. Development of an Appalachian deciduous forest succession model and its application to assessment of the impact of the chestnut blight. J. Environ. Manage. 5: 161-179.

Sollins, P., D. E. Reichle, and J. S. Olson. 1973. Organic matter budget and model for a southern Appalachian Liriodendron forest. EDFB/IBP-73/2. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

RELATIONSHIP OF FUSIFORM RUST INFECTION TO INTENSIVE CULTURE OF SLASH PINE[1]

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Abstract.--Growth was increased greatly by intensive culture in a southeastern Louisiana slash pine (Pinus elliottii Engelm.) plantation. At age 10, fusiform rust infection was 56 percent on stems in the intensive treatment compared to 18 percent in the control. The correlation between cankering and tree size was weak.

INTRODUCTION

Fusiform rust of southern pines, caused by the fungus Cronartium quercuum (Berk.) ex Shirai f. sp. fusiforme (formerly known as Cronartium fusiforme Hedgc. and Hunt ex Cumm.), is recognized as the most damaging disease of forest trees in the South. The incidence, distribution, and impact of fusiform rust have increased dramatically in much of the planted slash pine ecosystem since 1960 (Dinus and Schmidt 1977). The disease is particularly severe in young pine plantations because of the rust susceptibility of the two most widely planted species, slash (Pinus elliotii Engelm.) and loblolly pine (Pinus taeda L.).

A survey of economic damage due to fusiform rust in the South showed that stumpage losses amounted to $30 million annually, a loss of $750 million in finished wood products (Phelps 1974). Current losses in some areas of the South are serious, and there is a potential for greater future losses.

There is a trend in southern pine plantation management toward more intensive cultural practices in order to increase wood growth. The objective of this study was to evaluate the seriousness of fusiform rust on intensively cultured slash pine in southeastern Louisiana and to relate its incidence to diameter and height growth, mortality, and silvicultural practices.

METHODS

A study of intensive cultural management of slash pine was established in southeastern Louisiana. Four plots, each 0.30 ha in area, were established on a stream terrace site where a 40-year-old natural loblolly stand was making excellent growth. Oaks which are highly susceptible to fusiform rust are abundant in the forest surrounding the plots.

The soil of the study area is Kalmia very fin sandy loam, moderately well drained and moderately permeable. The climate is warm and humid during the summer and mild during the winter.

In the spring of 1970 one-year-old slash pine seedlings were planted on the plots at a spacing o 2.74 m x 3.66 m (997 trees per ha). The seed sour was fast-growing high-quality trees in the same ge eral area. A total of 299 trees were planted on each of the four plots. The site had been prepare several months earlier. The following cultural treatments were applied: Plot A--plowed before planting, irrigated, fertilized, brush control, an mowed; Plot B--same as Plot A except for irrigatio Plot C--fertilized and brush control; Plot D--control (no treatment).

Irrigation water was supplied to Plot A whenever available soil moisture dropped to 40 percent of field capacity. Fertilizers were applied to Plots A, B, and C one month after planting (7-40-6 57 g per tree), at age 5 (ammonium nitrate and treble superphosphate, 224 kg per ha each chemical and at age 8½ (8-8-8, 168 kg per ha). Plots A and B were mowed several times each year to control weed and grass competition. Brush on Plot C was controlled by cutting and by spraying with 2,4,5-T

Trees were measured and stand characteristics calculated annually through 10 growing seasons on the interior 0.1716 ha of each plot.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

[2] Professor, Associate Professor, and Graduate Assistant, respectively, Louisiana State University School of Forestry and Wildlife Management, Baton Rouge, Louisiana 70803.

Fusiform cankering on each standing tree was tallied during the ninth growing season (referred to for convenience as at age 8) and again at age 10. Each tree was classified into one of four classes: (1) no cankers; (2) one or more cankers on stem, none on limbs; (3) no canker on stem, one or more cankers on limbs; and (4) one or more cankers on stem and one or more cankers on limbs.

In statistical analysis, Chi square was used to test canker data, and correlation analyses were made to correlate cankering with tree dbh and height.

RESULTS

Stand characteristics, including percentages of stem- and limb-cankered trees, are shown in Table 1.

The more intensive the treatment, the greater was the average dbh, average height, and volume. Growth was apparently increased greatly by intensive culture. At age 10 the two plots (A and B) receiving the most intensive culture (plowing the site before planting, weed control, and fertilization) had four times as much cubic volume as the control.

The most intensively managed trees had the highest rate of stem cankering. At age 10, 56 percent of the trees on Plots A and B were stem-infected, while only 18 percent of the trees on control Plot D had stem galls. The percentage of trees on Plot C with stem cankers was twice the percentage found on Plot D. The geographic spread of stem infection was fairly uniform across each plot.

Limb cankers are potentially lethal if the canker is close enough to grow into the stem before the limb dies. Limb cankering in this study was more common on all plots than stem cankering. The relationship of intensive culture to limb cankering was weak or nonexistent.

The infection level at age 10 was significantly higher than at age 8, apparently due to new infections. By age 10, only 10 percent of the trees on Plots A and B had no cankers. Plot C had only 13 percent "clean" trees, and the control plot had 23 percent uninfected trees.

Mortality through age 10 was about 17 percent; it was nearly the same on each plot regardless of treatment. Recent mortality, between ages 8 and 10, was associated with stem cankering; every tree that died during this period had a stem canker at age 8. Mortality was apparently distributed at random throughout each plot.

The correlation between cankering and tree size was weak. Correlation coefficients for stem cankering and dbh on the four plots at age 10 varied from -0.11 to 0.16 and for stem cankering and height from -0.19 to 0.16. The average dbh and height of stem-cankered trees were approximately the same as that of trees without stem cankers. Stem infections were well distributed through the range of dbh classes.

DISCUSSION

The findings in this study are generally in agreement with those of earlier investigators. Intensive cultural management of slash pine by use of such practices as intensive site preparation, fertilization, and weed control increases fusiform rust infection (Gilmore and Livingston 1958, Dinus and Schmidtling 1971, Miller 1972, Malac and Brightwell 1973, May and others 1973, Hollis and others 1975, Powers and others 1975, Rowan 1977).

The progress of the disease during the past two years has been more rapid in all four plots than would have been predicted by using the age-eight percentages of trees with rust in the model developed by Schmidt and others (1979) for slash and loblolly pine plantations. Even on the control plot, rust incidence at age 10 is very high --78 percent. The study area is in a region of high rust-infection hazard for slash pine plantations (Squillace 1976).

Two adjacent loblolly pine plantation plots, established seven years before the slash pine plantation and treated similarly to Plots A and B, had only 8 percent stem infection at age 7 and 10 percent at age 17, much less than Plots A and B of the slash pine experiment at ages 8 and 10. Although exact comparison is not possible because of the different ages of the two plantations, on this site slash pine appears to be more susceptible than loblolly to rust infection, which is in general agreement with other research (Czabator 1971, Powers 1975).

The weak correlation between growth of individual trees and stem infection is generally in agreement with results of other investigations. Although Powers and others (1974) and Sluder (1977) found that stem growth of infected trees was reduced, others reported that rust does not affect growth significantly (Dell and Driver 1963, Dinus and Schmidtling 1971, Jones 1972). Perhaps, as thought by Holley and Veal (1977), the different results in the literature would be at least partially explained if investigators would rate severity of infection by measuring the percentage of the stem which is girdled.

Table 1.--Stand characteristics and fusiform rust infection in a slash pine plantation in southeastern Louisiana

Plot	Treatment	Trees per ha	Ave. dbh	Ave. ht.	Tot. vol.[1]	Infected trees Stem	Infected trees Limb	Infected trees None
		No.	cm	m	m^3/ha	Percent	Percent	Percent
			Age 8					
A	Intensive culture, incl. irrigation	839	13.4	9.01	37.9	35	66	26
B	Intensive culture, without irrigation	868	13.2	8.94	38.6	34	60	28
C	Brush control and fertilized	851	11.5	7.90	25.8	20	71	28
D	Control, no treatment	845	7.0	6.20	6.6	8	56	41
			Age 10					
A	Intensive culture, incl. irrigation	816	15.9	11.49	70.8	56	84	10
B	Intensive culture, without irrigation	833	15.8	11.55	70.6	56	87	10
C	Brush control and fertilized	839	14.1	10.21	52.8	36	87	13
D	Control, no treatment	828	9.4	7.96	16.2	18	78	22

[1] Volume is total entire stem inside bark.

It is questionable whether losses to increased rust infection negate the increased growth from intensive culture. In our intensively cultured plots rust infection has not as yet (through age 10) caused extensive mortality. Although losses due to rust may exceed the benefits due to increased growth from intensive culture, data from Brunswick Pulp Land Company's slash pine plantations in Georgia showed that intensive site preparation was economically justified in spite of associated increases of rust infection up to 50 percent (Anderson 1977).

Forest managers need help in deciding whether to abandon an infected plantation, to thin out infected stems, or to leave the plantation undisturbed until the end of a normal of a shortened rotation. Wells and Dinus (1978) showed that stem infection five years after planting was a reliable predictor of rust-associated mortality in loblolly and slash pine plantations at age 10 years. Belcher and others (1977) presented guidelines for choosing between removing or thinning rust-infected slash pine stands in Florida, based on number of trees per acre and percentage of stems infected. Application of these guidelines to our slash pine plots shows that Plots A and B would be reproduced, Plot C would be cleaned by thinning at age 16 to 20 and grown to rotation age, and Plot D would be held until the end of the rotation.

Although direct control of fusiform rust in pine plantations is now impossible, useful recommendations for a regional control strategy have been made by Schmidt and others (1977). They include such practices as suppression of susceptible oaks; delayed fertilization; planting rust-resistant species such as longleaf, shortleaf, or sand pines on high-hazard sites; planting rust-resistant hybrids or seed sources; consideration of a shelterwood regeneration system; having an unevenaged distribution among stands; planting uninfected seedlings; sanitation thinnings; pruning of infected branches when basidiospores are not present; careful controlled burning to avoid igniting resinous stem cankers; and utilization of infected portions of trees for tall oil, turpentine, and certain kinds of pulp.

LITERATURE CITED

Anderson, George.
1977. Fusiform rust management strategies in practice: site preparation. Pages 145-150 in R. J. Dinus and R. A. Schmidt, eds. Management of fusiform rust in southern pines. Symp. Proc. Univ. Fla., Gainesville, 163 p.

Belcher, H. J., W. J. Craft, Jr., W. D. Ericksen, and R. H. Ward.
1977. Fusiform rust management strategies in practice: plantation management. Pages 158-163 in R. J. Dinus and R. A. Schmidt, eds. Management of fusiform rust in southern pines. Symp. Proc. Univ. Fla., Gainesville, 163 p.

Czabator, F. J.
1971. Fusiform rust of southern pines--a critical review. USDA For. Serv., Res. Pap. SO-65, 39 p.

Dell, T. R., and C. H. Driver.
1963. The relationship of d.b.h. to fusiform rust cankering in old field slash pine plantations. J. For. 61:872.

Dinus, R. J. and R. A. Schmidt, eds.
1977. Management of fusiform rust in southern pines. Symp. Proc. Univ. Fla., Gainesville, 163 p.

Dinus, R. J., and R. C. Schmidtling.
1971. Fusiform rust in loblolly and slash pines after cultivation and fertilization. USDA For. Serv., Res. Pap. SO-68, 10 p.

Gilmore, A. R., and K. W. Livingston.
1958. Cultivating and fertilizing a slash pine plantation: effect on volume and fusiform rust. J. For. 56:481-483.

Holley, D. L., and M. A. Veal.
1977. Economic impact of fusiform rust. Pages 39-50 in R. J. Dinus and R. A. Schmidt, eds. Management of fusiform rust in southern pines. Symp. Proc. Univ. Fla., Gainesville, 163 p.

Hollis, C. A., W. H. Smith, R. A. Schmidt, and W. L. Pritchett.
1975. Soil and tissue nutrients, soil drainage, fertilization, and tree growth as related to fusiform rust incidence in slash pine. For. Sci. 21:141-148.

Jones, E. P.
1972. Fusiform rust affects planted slash pine. J. For. 70:350-352.

Malac, B. F., and C. S. Brightwell.
1973. Effect of site preparation on growth of planted southern pines. Union Camp Corp. Woodland Res. Note 29, 4 p.

May, J. T., S. Rahman, and R. H. Worst.
1973. Effects of site preparation and spacing on planted slash pine. J. For. 71:333-335.

Miller, T.
1972. Fusiform rust in planted slash pines: influence of site preparation and spacing. For. Sci. 18:70-75.

Phelps, W. R.
1974. How serious is fusiform rust in the South? For. Farmer 33(4):6-8.

Powers, H. R., Jr.
1975. Relative susceptibility of five southern pines to Cronartium fusiforme. Plant Dis. Rep. 59:312-314.

Powers, H. R., Jr., F. R. Mathews, and R. B. Hawes.
1974. Volume loss resulting from fusiform rust in young plantations of slash pine. USDA For. Serv., Res. Note SE-200, 7 p.

Powers, H. R., Jr., J. P. McClure, H. A. Knight, and G. F. Dutrow.
1975. Fusiform rust: forest survey incidence data and financial impact in the South. USDA For. Serv., Res. Pap. SE-127, 16 p.

Rowan, S. J.
1977. Fertilizer-induced changes in susceptibility to fusiform rust vary among families of slash and loblolly pine. Phytopathology 67:1280-1284.

Schmidt, R. A., A. E. Squillace, and B. F. Swindel.
1979. Predicting the incidence of fusiform rust in five- to ten-year-old slash and loblolly pine plantations. South. J. Appl. For. 3:138-140.

Schmidt, R. A., E. B. Cowling, and R. J. Dinus.
1977. Management of fusiform rust: recommendations for a regional rust control strategy. Pages 10-16 in R. J. Dinus and R. A. Schmidt, eds. Management of fusiform rust in southern pines. Symp. Proc. Univ. Fla., Gainesville, 163 p.

Sluder, E. R.
1977. Fusiform rust in loblolly and slash pine plantations on high hazard sites in Georgia. USDA For. Serv., Res. Pap. SE-160, 10 p.

Squillace, A. E.
1976. Geographic patterns of fusiform rust infection in loblolly and slash pine plantations. USDA For. Serv., Res. Note SE-232, 4 p.

Wells, O. O., and R. J. Dinus.
1978. Early infection as a predictor of mortality associated with fusiform rust of southern pines. J. For. 76:8-12.

APPENDIX I--REGISTRATION LIST

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Forest Service

**Southern Forest
Experiment Station**

New Orleans,
Louisiana

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Preservative Treatment of Hardwoods: A Review

Warren S. Thompson and Peter Koch

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SUMMARY

Increasing demand for softwoods, now supplying two-thirds of the wood volume annually treated with preservatives in the United States, presages major increases in hardwoods treated by the wood processing industry. The wood industries of Northern Europe, Australia and other areas where, as in this country, hardwoods are relatively abundant, are treating hardwoods for a wide range of products. This report reviews information basic to the treatment of some 56 American hardwood species with more than a dozen preservatives by variations of five pressure and four non-pressure treatment methods, together with data from softwood tests of materials and methods for which hardwood test results are not available. Also reviewed are data on impregnation of hardwoods for stabilization and to improve resistance to fire.

American hardwoods available for treatment are primarily in sizes and qualities unsuitable for high grade sawn products, but usable for crossties, posts, mine timbers, piling, pallets, laminated wood, fiberboards, and flakeboards. Some hardwood species with low specific gravities are easily treated at pressures and for durations similar to those used for softwoods of like density; heavy hardwoods are more difficult to treat and require longer impregnation times and higher pressures. Hardwood species differ widely, however, in their individual requirements.

Available chemicals and technology protect hardwood crossties from decay for service lives of 25 to 50 years; much current replacement in rail lines results from physical wear rather than decay. Somewhat shorter service lives may be expected from posts, which are normally more severely exposed, but for most species treatment can extend service life by 10 to 25 years. A number of non-pressure treatments and a variety of preservatives are widely used in post treatment.

For products in less severe exposure, the same chemicals can be used in lighter applications, or other chemicals selected to minimize undesirable effects such as altered color, stickiness, or toxicity to mammals. Thus life of boxes and pallets used for storage in damp situations can be greatly extended, and exposed woodwork can be impregnated for protection against insects and decay, and to improve fire resistance.

For applications in plywoods, particleboards, flakeboards, and fiberboards, chemicals must be compatible with adhesives which give strength to the panels. This requirement limits the choices of usable chemicals, but for most applications treatments with selected chemicals appear feasible, though some loss of strength may be involved. Further research is desirable in this field to more precisely define acceptable combinations of chemicals and adhesives.

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Preservative Treatment of Hardwoods: A Review

Warren S. Thompson and Peter Koch

INTRODUCTION

Hardwoods constitute about one-third of the timber resource of the United States, and occupy slightly over half of the Nation's commercial timberland. Occurring mainly in the East, they predominate over two-thirds of the eastern forest acreage. Although varying widely in many characteristics and often of high value in large, clear sizes, most hardwood trees tend to be small, crooked, and defective. Over much of the South they occupy sites on which pines could be grown more profitably (table 1, fig. 1). In both the South and the Northeast, stands of hardwoods, even on the better hardwood sites, contain much material of marginal value for traditional uses.

One way to make optimum use of the hardwood resource is to emphasize use of those products, such as fiberboard and particleboard, whose quality is not a direct function of stem quality. Another is to use small hardwoods for the production of treated products, such as fence posts, mine timbers, landscape timbers, and similar items, for which stem size and quality are not of critical importance.

Hardwood crossties currently account for about one-third of the 330 million cu ft of wood treated annually in the United States. This volume represents essentially all of the commercial production of treated hardwood products except for some mine timbers, highway posts, and oak piling. Other markets for treated wood, such as utility poles, fence posts, and sawn products, have long been satisfied by softwood species, principally the southern pines and Douglas-fir, because of their favorable form, availability in a wide range of sizes, and relatively uniform treating properties. This pattern of utilization tends to be unique to the United States. Treated hardwoods are used extensively for a range of products in Australia, New Zealand, Africa, Asia, Scandinavia, and parts of Europe where the supply of hardwoods is large relative to that of softwoods.

While treated commercially mainly for railroad ties and piling, hardwoods have been studied extensively in terms of their permeability to preservatives, their performance in ground-contact service, and the anatomical and biological factors which influence these properties. Related studies have provided information on impregnation of hardwoods for stabilization and fire resistance. Additional research is needed. Thus, Hatfield (1959) stressed the need for research to ascertain treatability of little used species of wood. He pointed out that lack of uniformity of treatment and inadequate penetration and retentions were common problems with many hardwood species. A substantial body of literature has evolved from the long-term and continuing interest in this subject. It identifies some of the problems and opportunities associated with the preservative treatment of hardwoods and the performance of hardwoods under adverse biotic conditions. Much of the literature describes results on hardwood species important on non-pine sites (table 2); because these results are, for the most part, pertinent to pine-site hardwoods, they are summarized in this report.

Table 1.—*The major hardwood species on pine sites in the South*

Common name	Botanical name
Ash, green	*Fraxinus pennsylvanica* Marsh.
Ash, white	*F. americana* L.
Elm, American	*Ulmus americana* L.
Elm, winged	*U. alata* Michx.
Hackberry	*Celtis* sp.
Hickory	*Carya* sp.
Maple, red	*Acer rubrum* L.
Oak, black	*Quercus velutina* Lam.
Oak, blackjack	*Q. marilandica* Muenchh.
Oak, cherrybark	*Q. falcata* Michx. var. *pagodaefolia* Ell.
Oak, chestnut	*Q. prinus* L.
Oak, laurel	*Q. laurifolia* Michx.
Oak, northern red	*Q. rubra* L.
Oak, post	*Q. stellata* Wangenh.
Oak, scarlet	*Q. coccinea* Muenchh.
Oak, Shumard	*Q. shumardii* Buckl.
Oak, southern red	*Q. falcata* Michx.
Oak, water	*Q. nigra* L.
Oak, white	*Q. alba* L.
Sweetbay	*Magnolia virginana* L.
Sweetgum	*Liquidambar styraciflua* L.
Tupelo, black	*Nyssa sylvatica* Marsh.
Yellow-poplar	*Liriodendron tulipifera* L.

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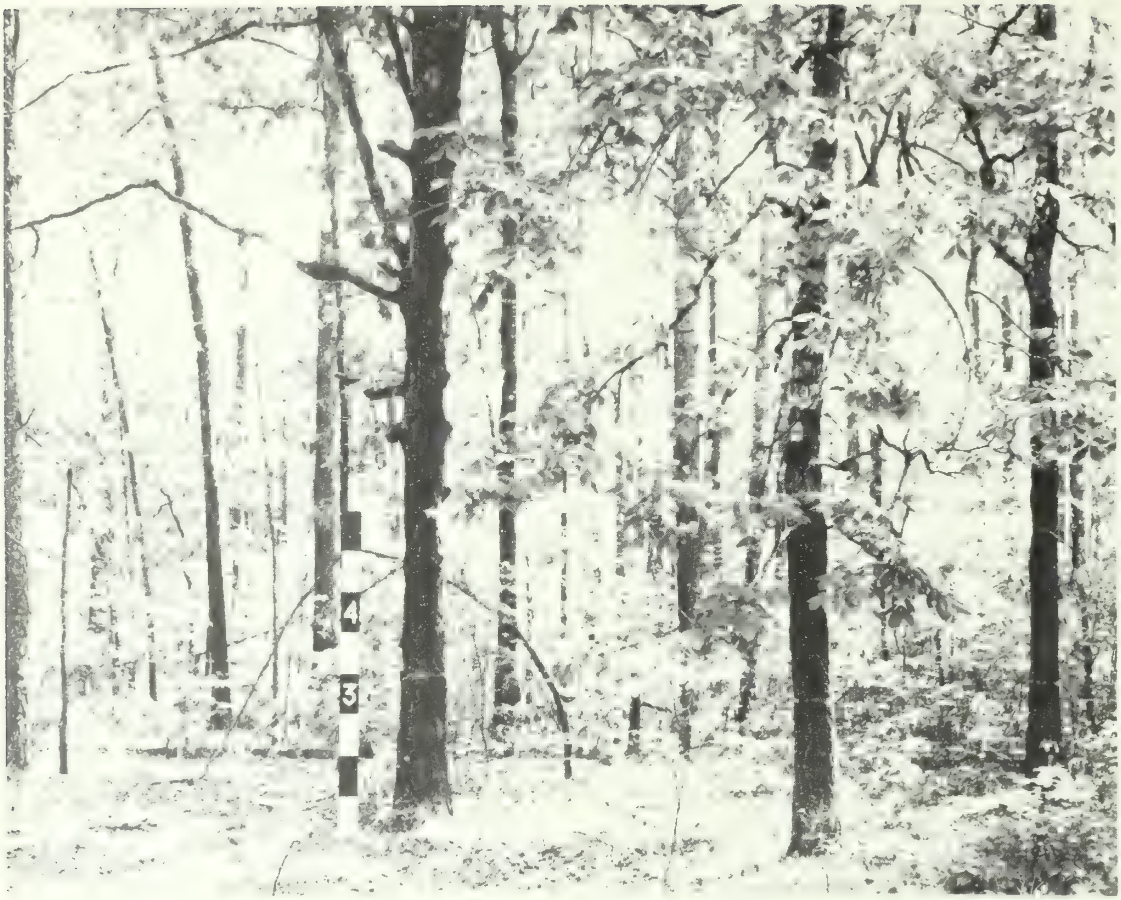

Figure 1.—*Typical stand of hardwoods mixed with southern pines. The hardwoods, deemed unmerchantable, have been girdled to deaden them and thereby accelerate growth of the pines.*

FACTORS AFFECTING TREATMENT QUALITY

Amenability of wood to preservative treatment depends upon numerous factors related to pre-treatment processing, such gross characteristics as sapwood thickness, and anatomical characteristics related to type, number, distribution, and size of its various structural elements. Variation in permeability to preservatives among species is almost always associated in part with differences in anatomical structure and the presence or absence of infiltrated materials. Variation within species may be due to many factors, including ratio of sapwood to heartwood, moisture content differences, and tree-to-tree differences in the amount and distribution of tyloses.

The fact that heartwood of all species is much less permeable than sapwood has a profound influence on the quality of preservative treatments of sawn products. Properly seasoned wood of all species is more easily penetrated by pressure processes than unseasoned wood; the drier the wood the deeper the penetration. Radial penetration of water-borne preservatives virtually stops at the point where free water is present. Freshly cut wood of most species can be properly treated only with difficulty, if at all.

Wood-Related Factors

Anatomical Structure.—The size, distribution, and condition of vessels are the most important basic factors affecting the preservative treatment of hardwoods. (See McMillin and Manwiller (in press) for an atlas of anatomical features of stemwood from the hardwood species listed in table 1.) Open pores (vessels) are the principal avenues for initial penetration in such species as red oak. White oak and other species whose vessels are wholly or partly occluded by tyloses or infiltrated substances are difficult to treat. The degree to which tyloses block penetration of preservatives varies with species. Tyloses in a few species, including American beech and some species of oak and hickory, are thin-walled and can be ruptured during treatment of the wood, thus permitting penetration. In other species tyloses are scattered and their effect on pre-able 2.—*Hardwood species common on non-pine sites, for which preservative treatment data are available*

Common name	Botanical name
spen, bigtooth	*Populus grandidentata* Michx.
spen, trembling	*P. tremuloides* Michx.
asswood	*Tilia* sp.
eech, American	*Fagus grandifolia* Ehrh.
irch, river	*Betula nigra* L.
irch, sweet (or black)	*B. lenta* L.
irch, white	*B. papyrifera* Marsh.
irch, yellow	*B. alleghaniensis* Britton
lackgum	*Nyssa sylvatica* Marsh.
ox elder	*Acer negundo* L.
utternut	*Juglans cinerea* L.
herry, black	*Prunus serotina* Ehrh.
ottonwood	*Populus deltoides* Bartr.
lm, slippery	*Ulmus rubra* Muhl.
lm, rock	*U. thomasii* Sarg.
lm, cedar	*U. crassifolia* Nutt.
ickory, mockernut	*Carya tomentosa* Nutt.
ickory, shagbark	*Carya ovata* (Mill.) K. Koch
oney locust	*Gleditsia triacanthos* L.
aple, silver[1]	*Acer saccharinum* L.
aple, red[1]	*A. rubrum* L.
aple, sugar	*A. saccharum* Marsh.
ak, bur	*Quercus macrocarpa* Michx.
ak, California blue	*Q. douglasii* Hook. & Arn.
ak, overcup	*Q. lyrata* Walt.
ak, pin	*Q. palustris* Muenchh.
sage-orange	*Maclura pomifera* (Raf.) Schneid.
ecan	*Carya illinoensis* (Wangenh.) K. Koch
ecan, bitter	*C. aquatica* (Michx. f.) Nutt.
ersimmon	*Diospyros virginiana* L.
oplar, aspen	*Populus* sp.
edgum	*Liquidambar styraciflua* L.
ycamore	*Platanus occidentalis* L.
upelo, water	*Nyssa aquatica* L.
alnut, black	*Juglans nigra* L.
illow, black	*Salix nigra* Marsh.

[1] oft maples.

ervative treatment is proportional to their frequency Teesdale and MacLean 1918).

When vessels are blocked by tyloses or extraneous eposits, penetration may occur through such proenchymatous tissues as fibers. Teesdale and MacLean 1918) concluded that hardwood rays, unlike those of oftwoods, are not important in transverse distribution f preservatives. Behr et al. (1969), however, reported hat, while longitudinal parenchyma is unimportant s a reservoir for preservative in most species, ray arenchyma retains significant amounts and is an mportant avenue for radial penetration in some species. imilarly, Greaves and Levy (1978) found CCA-type reservative in relatively high concentrations in ray issue of several hardwoods. Bosshard (1961) likewise ound creosote in ray tissue of beech—both as droplets nd as a film on lumen walls. In areas of low retention he rays held most of the creosote. Narrow rays seem ore important in preservative movement than wide ays such as occur in oak and beech.

Passage of preservatives through fibers and other prosenchymatous tissue is much slower and far less extensive than through vessels because hardwood pits are poorly developed. Teesdale and MacLean (1918), however, found it relatively important in certain species, such as hickory. They found the type and arrangement of the various structural elements more important to treatability than earlywood-latewood differences.

All recent work confirms Teesdale and MacLean's (1918) finding that vessels are important in the preservative treatment of hardwoods. Behr et al. (1969) reported latewood vessels more important as reservoirs of preservative than earlywood vessels, presumably because of the smaller diameter of the former; the ability of a capillary, such as the lumen of a vessel, to hold liquid varies inversely with diameter of the capillary. Perforation plates between vessels were often coated with or contained preservative when the vessel was not filled. These investigators stated that the magnitude of preservative adhesion to wood may be of importance in determining its effectiveness and contribute to differences in efficacy among species.

Teesdale and MacLean (1918) found fibers to be unimportant as avenues for preservative penetration unless the vessels were occluded. Reports by Liese (1957) that hardwood pit membranes are incapable of transmitting preservative because they contain no pores tend to support this conclusion. Côté (1963), however, observed that, while no openings were visible in basswood pits, the pits were nonetheless permeable to treating solution. Ernst (1964) found that fibers are important in determining the permeability of certain hardwoods, and Behr et al. (1969) found evidence of fiber-to-fiber movement of liquids via pits and concluded that fibers, as well as vasicentric and vascular tracheids in species containing these elements, are important reservoirs of preservative in treated wood. It appears, therefore, that the permeability of most hardwoods is attributable largely to their vessels, the fibers contributing little because of small lumen size and poor network of interconnecting pits—but this generalization is not true of all hardwoods.

Lack of agreement among investigators on the importance of different cell and tissue types to wood permeability may be due in part to natural variations among species. Thus, rays apparently are important avenues for preservative penetration in some species and not in others (Behr et al. 1969). Work of Levy and Greaves (1978) and Dickinson et al. (1976), who studied the distribution of preservative among tissue types in several species, revealed that each species has its characteristic distribution pattern. Some of the 10 hardwoods studied treated primarily through the rays, for others the principal avenues for penetration were the vessels, and for still others both rays and vessels were important.

Species.—Teesdale and MacLean (1918) studied creosote penetration and retention in heartwood and a few sapwood samples of 25 hardwood species. All samples were similarly seasoned to identical moisture contents, and were similarly treated. On the basis of their results they grouped the species into three treatability classes (table 3).

Sribahiono et al. (1974) reported that species could be placed less laboriously in the three classes defined by Teesdale and MacLean (1918) by treating specimens with 0.5 percent keystone oil red dye in mineral spirits by a vacuum impregnation technique and determinir longitudinal penetration of the dissected specimens.

Siau et al. (1978) classified southern hardwoods int similar groups based on the ease of treatment wit methyl methacrylate monomer using a vacuum proces Ease of treatment was evaluated in terms of the fra tional void volume filled by monomer (table 4.)

They reported that treatability was generally we correlated with permeability and varied inversely wit

Table 3.—*Tested species grouped according to difficulty of impregnation (Teesdale and MacLean 1918)*

Basis for grouping	Group I	Group II	Group III
Depth of penetration at 100 psi[1]			
Lateral	Complete	Variable	. . . .
Longtitudinal, inches	>8	4-8	2.5−
Retention of creosote, pcf[2]	12+	7-10	6−
Tyloses	Absent	Present, closure incomplete	Vessels occluded by tyloses
	Ash, green	Aspen, bigtooth	Beech
	Ash, white	Chestnut	Oak, bur
	Basswood	Elm, rock	Oak, white
	Beech	Hackberry	Sweetgum
	Birch, river	Hickory[3]	
	Birch, sweet	Maple, silver	
	Birch, yellow	Maple, sugar	
	Cherry	Sycamore	
	Elm, American	Willow, black	
	Elm, slippery		
	Hackberry[4]		
	Maple, silver[4]		
	Oak, chestnut		
	Oak, red		
	Sweetgum[4]		
	Tupelo gum[4] [5]		

[1] Psi—pounds per square inch.

[2] Pcf—pounds per cubic foot.

[3] Vessels closed by tyloses, but creosote penetrated through fibers and tracheids.

[4] Samples were sapwood; all others were heartwood.

[5] Probably *Nyssa sylvatica* Marsh.

Table 4.—*Southern hardwoods grouped by difficulty of impregnation with methyl methacrylate monomer by vacuum process (Siau et al. 1978)*

Easy (0.8+ of voids filled)	Moderate (0.4-0.8 of voids filled)	Difficult (less than 0.4 of voids filled)
Maple, red	Ash, green	Hackberry
Sweetbay	Elm, American	Oak, black
Sweetgum	Elm, winged	Oak, blackjack
Tupelo, black	Hickory	Oak, post
Yellow-poplar	Oak, cherrybark	Oak, white
	Oak, laurel	
	Oak, northern red	
	Oak, scarlet	
	Oak, Shumard	
	Oak, southern red	
	Oak, water	

specific gravity. Thus, the average specific gravities of the "easy", "moderate", and "difficult" groups were 0.51, 0.69, and 0.74, respectively.

Cook (1978) studied directional penetration by pressure impregnation of short bolts in a commercial retort with a 5.3 percent solution of pentachlorophenol in a petroleum solvent, using resin coatings to restrict preservative movement to the transverse or longitudinal directions. Although his treating schedule was too mild to provide for penetration into refractory species, the method has promise for use in future studies.

Permeability.—Permeability of wood to liquids is a function of anatomical structure. The presence of cell deposits and incrustations on the membranes of pits connecting wood cells is a major factor in resistance to penetration of liquids. Various methods of improving permeability have been tried, including chemical treatments to extract material from the pit membrane or degrade the pit membrane itself. Sodium chlorite, pulping liquors, acids and bases have been tested (Nicholas 1977). All degrade the wood and reduce its strength. None are effective in heartwood, where permeability is most limited.

Biological treatments using fungi and bacteria, while used successfully on southern pine, are also effective only in sapwood. Enzymes (cellulase, pectinase, etc.) have been successfully used to improve permeability, without strength loss, of sapwood but not of heartwood. Greaves and Barnacle (1970), for example, reported that infection by microorganisms increased the permeability of slash pine and *Eucalyptus diversicolor* to creosote. This effect was attributed in both instances to depletion of cell contents in ray tissue and alterations of bordered pits by enzymes of invading organisms.

Cech (1971) and Cech and Huffman (1972) improved the seasoning and treating properties of refractory woods such as spruce (*Picea* sp.) by compressing boards from 5 to 15 percent of their thickness between pressure rolls (table 5). Nicholas and Siau (1973) applied the process to Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) with equal success. Retention and penetration of creosote in spruce increased more than 50 percent when Cech and Huffman (1972) compressed boards 15 to 20 percent before treatment.

Cech (1971) hypothesized that the compression treatment increased premeability by damaging pit membranes. This theory is supported by electron micrographs showing splits in some pit membranes, and by Nicholas and Siau's (1973) observation that radial compression is more effective than tangential.

Tesoro and Choong (1976) measured the permeability of nine hardwoods and three softwoods to both liquids and gas. For every species except cottonwood, heartwood was less permeable than sapwood. Longitudinal water permeability of the hardwood specimens that had been dried and resaturated was nine times greater than that of specimens that had never been dried. For soft maple the increase was 59-fold. Similar results were not obtained with softwoods because of extensive pit aspiration during drying.

Table 5.—*Effect of transverse compression on retention and penetration of creosote into eastern white spruce (Picea glauca* (Moench) Voss*) (Cech and Huffman 1972)*

Compression	Retention		Penetration	
		Fraction of controls	Fraction of cross section	Fraction of controls
percent	*pcf*[1]	*percent*	*percent*	*percent*
0	3.4		20.8	
10	4.6	135.3	24.6	118.3
15	5.5	161.8	32.8	157.7
20	5.2	152.9	31.5	151.4

[1] Pounds per cubic foot.

In the Tesoro and Choong (1976) study, correlation was high between various measures of permeability and treatability of all hardwoods except semi-ring porous species, notably black willow and cottonwood. This was not true, however, for softwoods. Interestingly, permeability to water was the best indicator of treatability with copper sulfate, while permeability to gas was the best index for predicting treatability with creosote.

In other studies involving nine hardwoods and six softwoods Tesoro et al. (1966) found positive linear relationships between the logarithm of lateral air permeability and both creosote retention and depth of penetration. The correlation coefficient for permeability and retention level for the pooled results of hardwoods and softwoods was 0.847; that for permeability and depth of penetration was 0.687. Both values were significant at the 1 percent level. There was no significant difference between the regression curves for hardwoods and softwoods at the 1 percent level. Their data are presented in table 6.

Thomas (1976) conducted anatomical studies in an effort to determine the differences among sweetgum, hickory, and blackgum heartwood in degree of penetrability to fluids. He reported that blocking of intervessel pits, isolation of vessels from fibers, parenchyma, tyloses, and low vessel volume induced flow along heartwood fibers. He attributed the fact that hickory is moderately difficult to treat to the minor role played by vessels in preservative distribution, due to tyloses which obstruct liquid flow.

Tyloses and encrusted pit membranes in both vessels and fibers of sweetgum heartwood were found to halt liquid flow effectively, thus accounting for the difficulty of treating this species. By contrast, black tupelo heartwood lacks tyloses, contains little encrustation, and is relatively easy to treat.

Longitudinal and transverse permeabilities of cottonwood were determined with nitrogen gas by Isaacs et al. (1971) to fall within the range of 0.109-13.81 darcys and 0.0014-0.0715 darcys, respectively[1]. Surprisingly, sapwood of cottonwood was less permeable than its heartwood. Permeability was correlated with specific gravity in heartwood but not in sapwood. Permeability was not correlated with extractive content nor with treatability with creosote. Retentions of creosote varied widely among samples.

Measurements of the relative and absolute permeability[1] of willow, sweetgum, and tupelo were made by Tesoro et al. (1972). They reported that the pattern of relative permeability of these woods resembled that of oil-bearing rock. When the relative permeability to water was zero, that to oil was not equal to one. For any given level of saturation, the sum of the relative permeabilities of the two fluids was always less than unity except where the flowing phase—either oil or water—completely saturated the specimen. A small increase in the level of oil saturation resulted in a major increase in the relative permeability to oil; likewise, a small decrease in water saturation of a specimen occasioned a sharp decrease in the relative permeability of wood to that fluid. Oil flow through a specimen displaced only a small portion of the water.

Movement of liquids into hardwoods and the an tomical and physical factors affecting it have bee reported by Rosen (1974a, 1974b, and 1975a) an Rosen and vanEtten (1974). They found that boun moisture uptake is proportional to the square roo of the time required for bound water to increase fro the initial moisture content to two-thirds of the fib saturation point. Bound and free uptake of organ solvents by red oak and black walnut were linea with the square root of time up to two-thirds maximum adsorption.

Processing-Related Factors

Quality of treatment, as judged by preservativ distribution and retention, varies widely among specie because of the factors discussed above. Variation i treatment quality within a species, while perhaps du in part to some of these same factors, is most influence by pretreatment processing and by treating cond tions themselves. Wood may be incised and must b dried preparatory to all except diffusion treatments The results achieved in pressure treatments are func tions of the pressure and temperature employed. Treat ment duration is important in both pressure an non-pressure processes.

Treating Conditions.—Within limits, preservativ retentions achieved by pressure treatments vary in versely with moisture content of the wood and directl with temperature and pressure. Thus, for example

Table 6.—*Mean transverse air permeabilities and retentions and depth of penetration of creosote for selected wood species*[1]. *(Adapted from Tesoro et al. 1966.)*

Species	Type of wood	Permeability	Retention	Depth of penetration
		cm³/sec-cm-atm	*g/cc*	*mm*
Balsam fir (*Abies balsamea* L. Mill.)	Sapwood	0.0094	0.19	2.86
Maple	Heartwood	.0110	.31	6.94
Hickory	Sapwood	.0036	.15	4.34
Hickory	Heartwood	.0032	.19	5.15
Ash	Sapwood	.0130	.23	4.70
Larch (*Larix* sp.)	Sapwood	.0037	.13	2.05
Larch	Heartwood	.0031	.05	0.66
Spruce	Sapwood	.0072	.23	3.88
Pine (*Pinus* sp.)	Sapwood	.0350	.36	
Pine	Heartwood	.0068	.14	
Aspen	Heartwood	.0590	.44	4.95
Cherry	Heartwood	.0062	.06	1.08
Douglas-fir	Sapwood	.0440	.17	5.78
Douglas-fir	Heartwood	.0022	.14	2.17
Oak	Heartwood	.0062	.05	.73
Mahogany (*Swietenia mahogani* Jacq.)	Heartwood	.0018	.02	.19
Baldcypress (*Taxodium distichum* (L.) Rich.)	Heartwood	.0390	.44	6.03
Teak (*Tectona grandis* L. F.)	Sapwood	.0008	.04	.17
Teak	Heartwood	.0000	.03	.20
Basswood	Heartwood	.1900	.51	6.36

[1] Each measurement is the average for four replicated samples.

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[1] The Darcy unit is a measure of permeability; high values indicate greater permeability than low numbers. Relative permeability values are not corrected for viscosity of the flowing medium; absolute permeability is relative permeability multiplied by the viscosity of the flowing medium.

direct relationship has been found between treating ressure within the range of 0 to 800 psi and preservaive retention (Walters 1967). Retentions also varied irectly with preservative temperature, so that inreasing temperature from 100 to 200°F effected a 8 percent increase in adsorption. Siau (1970) likewise as shown that adsorption of preservative by wood pecies having a range of permeabilities increases irectly with treating pressure and inversely with soluion viscosity. Retentions obtained with the various pecies were in the same order as their permeabilities. etentions of 91 and 78 percent of void volume were chieved by the full-cell process with Douglas-fir and hite oak heartwood, respectively, when a pressure of ,000 psi was used.

The relationship between treating pressure and preervative adsorption is anchored to wood structure. he size openings available for preservative movement wood varies widely among species and between sapood and heartwood. Size of openings determines the ressure required to insure an adequate treatment. iau (1971) calculated the pressure needed to force arious liquids through different pore sizes. He found hat the smallest pore that could effectively be filled ith water using the highest gauge pressure available t most commercial treating plants (200 psi) has a adius of 0.10 μm (Nicholas and Siau 1973). Stamm 1967, 1970) showed that many species have pore radii that are considerably smaller than that value. The effect of pore size on adsorption is shown dramatically in figure 2. The breaks in the curves (e.g., Douglas-fir) were shown by Nicholas and Siau (1973) to correspond to radii of pores through which the liquid could be forced by the pressure involved.

The effect of pressure is not necessarily the same for all species. Akhtar and Walters (1974) reported changes in retention in white oak from 4.59 pcf to 8.67 pcf, a difference of 89 percent, accompanied pressure increases in the range of 150 to 600 psi. For red oak, however, the corresponding increase over the same pressure range was 17 percent, from 16.66 pcf to 19.48 pcf. Differences between these species were confirmed by Rosen (1975b) at pressures from 200 to 2015 psi; increased retention with higher pressure was more pronounced for white oak than for red oak. Degree of impregnation, expressed as a percentage of the theoretical maximum retention, was linearly related to the logarithm of treating pressure.

Incising.—Relatively few wood species are sufficiently permeable for consistently uniform penetration and desired retention of preservatives. To expedite penetration and retention of preservative solution, wood surfaces of moderately to difficultly permeable species may be incised by roller-mounted knives, leaving variously patterned longitudinal cuts, usually less than 1 inch long and 1 inch deep (fig. 3). Many sawn

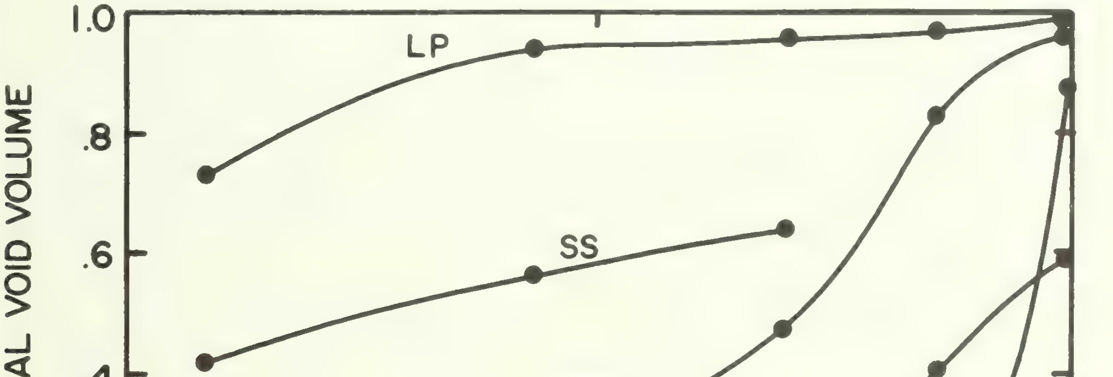

Figure 2.—*Effect of treating pressure on permeability of several species to a hydrocarbon oil with a viscosity of 1.0 poise. LP denotes longleaf pine (*Pinus palustris *Mill.); SS, sitka spruce (*Picea sitchensis *(*Bong.*) Carr.); WRC, western redcedar (*Thuja plicata *Donn.); DF, Douglas-fir; WO, white oak. (Drawing after Siau 1970.)*

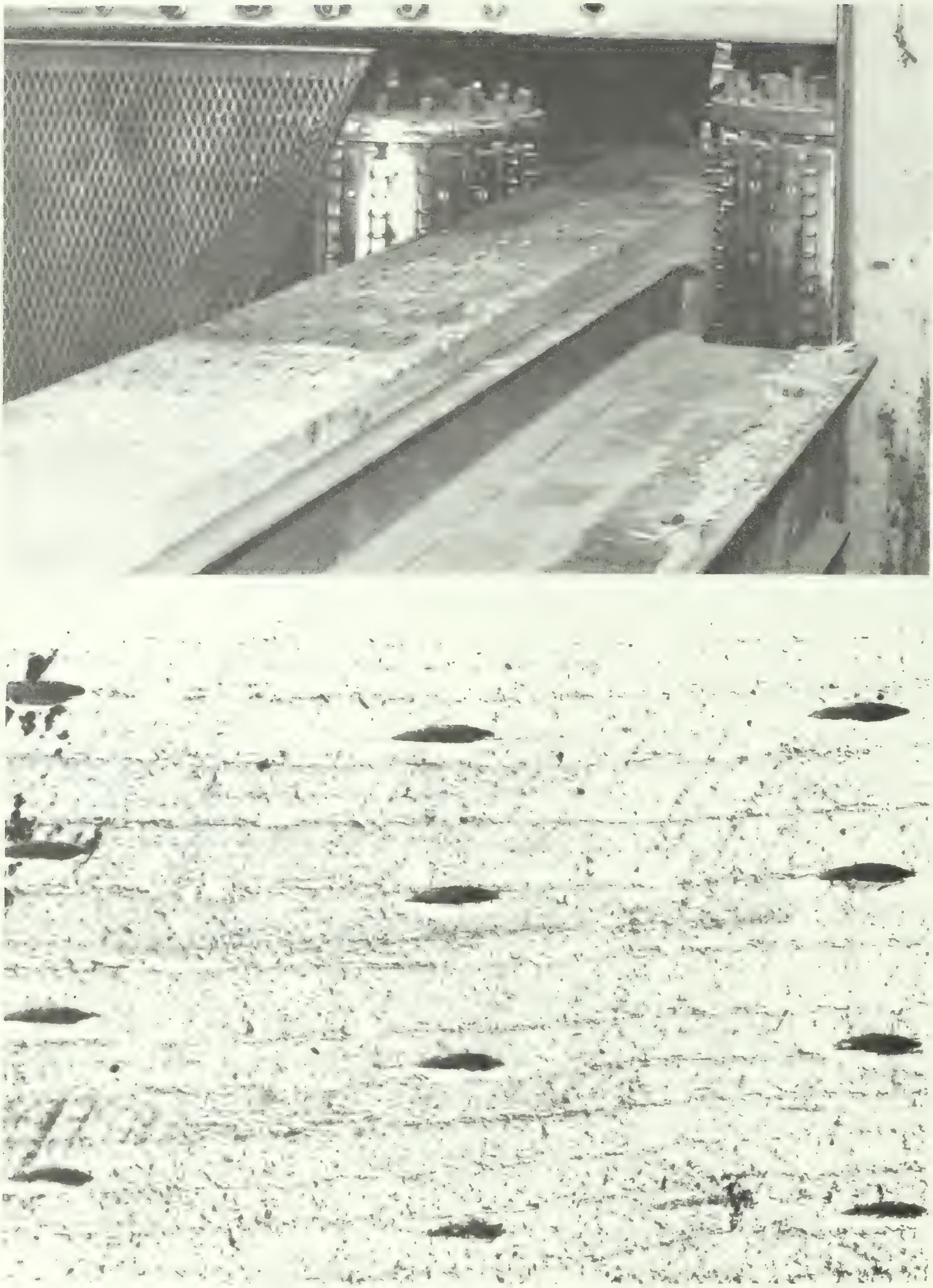

Figure 3.—*Incising of refractory species to increase retention and depth of penetration of preservative. (Top) Greenlee drums designed for 56 incisions per square foot. (Bottom) Incisions measure about ¾-inch long and ¾-inch deep.*

products, hardwood crossties among them, are routinely ncised, regardless of species, because sapwood of some species and heartwood of most hardwoods are difficult to treat adequately. Round stock may or may not be ncised depending upon species.

Perrin (1978) has reviewed the history and practice of ncising. That it has accomplished its original purpose to increase penetration and retention into refractory species of wood (Bellman 1968) is attested to by numerous reports. Increases in treatment quality effected by incising of eucalyptus (Johanson 1975), Japanese oak (Anonymous 1955), and other hardwood species (Kanehira and Taniguchi 1960; Chudnoff and Goytia 1967) clearly demonstrate the importance of the process. Typical data from Graham (1956) on the effects of incising on preservative treatment of six softwoods are given in table 7. Incising improved both penetration and retention of creosote in several of the species. Similar results have been reported earlier by MacLean (1930).

Beneficial effects of incising on checking were reported by Harkom (1932) who found incising at the rate of 56 incisions per square foot before air-drying reduced serious checking by 21, 23, and 61 percent in birch, maple, and beech ties. Henry (1970) and Franciosi (1956, 1967) found that the beneficial effects of incising were still evident after 10 to 18 years in service. Graham and Estep (1966), however, reported that checking after treatment in all incised Douglas-fir spar crossarms in their study exposed untreated heartwood.

Conditioning.—Maximum preservative retention is a negative function of moisture content for woods of the same specific gravity. Walters (1967) found that sweetgum specimens with a moisture content of 8 percent adsorbed 2.3 times as much preservative during high-pressure treatments as specimens with a moisture content of 25 percent.

Conditioning treatments are applied to reduce the moisture content of stock to a level at which it will accept the requisite amount of preservative and permit radial penetration at least to the deepest limit of the zone within which samples are collected for retention determinations. Air-drying is the most common method of conditioning large items, such as crossties. Because air-drying requires large inventories of stock, Boulton drying and vapor drying are being used by an increasing number of plants.

Boulton drying is applicable to any stock destined for treatment with an oily preservative. Basically, the process involves the use of the preservative itself as a heat-transfer medium and a vacuum to reduce the boiling point of water. Temperatures up to 220°F and vacuum of 14 to 24 inches of mercury are employed (Graham 1980). Vacuums in this range correspond to boiling points of water of 152°F to 182°F. Duration of the Boulton process varies with product size and initial moisture content, but typically ranges from 20 to 60 hours. Wood can be dried to a moisture content below the fiber saturation point by this method. Representative moisture content data for Boulton drying of Douglas-fir pole sections for 43 hours are shown below (Graham and Womack 1972; Graham 1980). Kiln-drying for 43 hours provided an almost identical moisture gradient.

Inches from surface	Initial moisture content	Moisture content after Boulton drying
	Percent	
1	103	31
2	71	31
3	44	35
4	34	33
5	34	32
6	33	30

Similar results can be obtained with hardwood crossties, although the target moisture content for this product is generally 40 to 45 percent, somewhat higher than that shown for Douglas-fir.

Vapor drying has been used almost exclusively to condition hardwood ties since its development in the

Table 7.—*The effect of incising on the creosote treatment of several Oregon conifers (Graham 1956)*[1]

Species	Average preservative penetration		Average preservative retention	
	Incised	Nonincised	Incised	Nonincised
	inches		*pcf*	
Libocedrus decurrens Torr.	1.0	0.7	17.1	12.1
Abies magnifica A. Murr.	.9	.6	14.7	10.7
Abies concolor (Gord. & Glend.) Lindl. ex Hildebr.	1.5	1.5	17.8	19.5
Tsuga heterophylla (Raf.) Sarg.	1.2	1.1	16.1	16.0
Tsuga mertensiana (Bong.) Carr.	.7	.6	14.3	14.0
Picea sitchensis (Bong.) Carr.	1.4	1.3	13.5	11.0

[1] These conifers, like most pine-site hardwoods, are refractory and must be incised to get acceptable retentions of preservatives. The retention values reflect heavy preservative adsorption in a thin band of sapwood.

1940's. Carried out in the preservative treatment retort, the process exposes the wood to hot vapors of organic solvents such as xylene. Drying temperature depends upon the composition of the heat transfer medium used, but generally is within the range of 280° to 320°F. Drying times are short, generally 12 hours or less. Typical data showing the reduction in moisture content with time effected by vapor drying of a charge of green oak crossties are shown in table 8. According to Hudson (1949), moisture content bears a linear relationship to vapor drying time that is expressed by the equation:

$$\text{Log } C = -0.0304t + \text{Log } I,$$

where C is final moisture content, t is drying time, and I is initial moisture content.

Steaming, though less efficient than Boulton or vapor drying, may also be used to condition certain species of wood. The unseasoned wood is exposed to live steam at 245°F, followed by vacuum. Duration varies with size and moisture content, but is usually 8 to 20 hours. A volume of water equivalent to 4 to 8 pounds per cubic foot is typically removed. Assuming an initial moisture content of 80 percent, an 8-pound removal per cubic foot would leave wood having a specific gravity of 0.52 with a residual moisture content of 56 percent. Steaming is not permitted with oaks, the species group that comprises at least 50 percent of the volume of hardwoods that receive commercial preservative treatments annually.

Stock intended for non-pressure treatment is normally air-dried to 30 percent moisture content or less.

Table 8.—*Data for typical charge of oak crossties seasoned by the vapor-drying process (Hudson 1949)*[1]

Time	Cumulative water removed	Moisture content
hours	*pounds/cu ft*	*percent*
	Wood Exposed to Hot Vapor	
0	. .	77.6
1	.26	76.9
2	1.12	74.5
3	2.13	71.7
4	3.12	69.0
5	3.86	66.7
6	4.86	64.2
7	5.61	62.1
8	6.42	59.9
9	7.19	57.8
10	7.93	55.8
11	8.51	54.2
12	9.14	52.5
	Vacuum After Heating in Vapor	
2	11.50	46.0
	Final Vacuum	
1	12.38	43.6

[1] Charge was composed of 2,804 cu ft (814 ties) and retained an average of 0.48 pcf of drying agent.

WOOD PRESERVATIVES

Preservatives of the Past and Present

The first successful wood preserving process w
patented by Kyan in 1832. It involved immersing wo
in a solution of mercuric chloride. Similar use of copp
sulfate and zinc chloride followed in 1837 and 18
respectively. Creosote was patented as a preservat
in 1836; but it was not used commercially until 18
when Bethell developed a pressure process for inje
ing preservatives into wood.

Creosote was first used in the United States in 18
to treat railroad ties, and it and its solutions wi
coal tar and petroleum continue to be used for th
purpose almost to the exclusion of other preservativ
Pentachlorophenol was patented as a preservative
1931, but was little used until World War II, wh
creosote was in short supply. Other oil-borne wo
preservatives include copper naphthenate and copp
8-quinolinolate, patented in 1948 and 1963, resp
tively, but little used commercially at present. Copp
naphthenate has the potential for "heavy-duty" use
ground-contact service, but its undesirable physic
properties and high cost have limited its use. Copp
8-quinolinolate is also too expensive for wide-sca
commercial use, but is used to treat container sto
used by the food industry, since it is the only pres
vative that is permitted in contact with food product

Fluor-chrome-arsenate-phenol is the oldest of th
commercially successful water-borne salt formulation
having been patented in 1918. It was followed, in ord
by acid copper chromate (ACC) in 1928, chromat
copper arsenate (CCA) in 1938, and chromated zi
chloride (CZC) and ammoniacal copper arsenate (AC
in 1939. The commercial use of fluor-chrome-arsenat
phenol has decreased from about 7 million pounds
1966 to less than 250 thousand pounds in 1977. Chr
mated zinc chloride and acid copper chromate are us
mainly on lumber for above-ground service; togeth
they accounted for less than 1 percent of wood treat
in 1977 (American Wood Preservers' Association 197
CCA and ACA are widely used by the wood preservi
industry today.

Creosote, pentachlorophenol, and two inorganic sa
formulations, CCA and ACA, the only preservativ
widely used commercially for ground contact servi
in the United States, accounted for 47, 24, and
percent of the 330 million cubic feet of wood treat
in the United States in 1978[2]. Creosote is used principa
ly to treat railroad ties, piling, and poles, accountin
for 97, 83, and 28 percent of these products in 197

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[2] U.S. Department of Agriculture. 1980. Biological and econom
assessment of pentachlorophenol, inorganic arsenicals, ar
creosote. Report of the USDA-States-EPA Preservative Cher
icals Assessment Team. Final draft report.

Table 9.—*Volume of wood treated in 1978 by product and preservative*[1]

Product	Preservative			
	Creosote	Penta	CCA and ACA	Total
	thousand cu ft			
Railroad ties	103,138	449	3,498	106,085
Poles	18,237	41,905	4,038	64,180
Piling	9,993	1,154	943	12,090
Lumber, timbers	10,780	21,209	73,317	105,306
Fence posts	4,584	10,983	4,461	20,028
Other	7,855	4,296	7,646	19,797
Total	154,587	79,996	92,903	327,486

[1] U.S. Department of Agriculture. 1980. Biological and economic assessment of pentachlorophenol, inorganic arsenicals, and creosote. Report of the USDA-States-EPA Preservative Chemicals Assessment Team. Final draft report.

(table 9). The principal products treated with pentachlorophenol are poles, posts, and sawn products, other than ties, 64, 55, and 20 percent of which are treated with that preservative. CCA and ACA jointly account for 70 percent of all lumber treated in the United States and the use of these preservatives for poles, posts, and piling is increasing rapidly.

Creosote is used straight or blended with coal-tar or petroleum. Its use with petroleum is confined almost entirely to tie production. Pentachlorophenol may be applied as a solution in any of a wide range of petroleum solvents, depending upon the end use of the product. It is also applied, mainly on utility poles, in such volatile solvents as methylene chloride and liquified petroleum gas.

ACA is an ammoniacal solution of arsenic and copper which, upon evaporation of ammonia, forms an insoluble precipitate of copper arsenate in the wood. CCA is an acid solution of copper oxide, chromic acid, and arsenic acid which react *in situ* to form a complex of relatively insoluble precipitates. Various salts of chromium and copper may be used instead of chromic acid and copper oxide in formulation of CCA preservatives. Three formulations designated as Type A, Type B, and Type C, are currently recognized by the American Wood-Preservers' Association (1977). Their compositions are shown below.

Ingredient	Percent composition		
	Type A	Type B	Type C
CrO_3	65.5	35.3	47.5
CuO	18.1	19.6	18.5
As_2O_5	16.4	45.1	34.0

CCA Type C is most widely used and it probably will, in time, entirely displace the other two formulations.

While creosote and waterborne salts are equally efficacious in preventing biological deterioration, tests show that salt-treated wood is much more prone to split, check, and deteriorate with weathering. Either preservative prevents decay in crossties, but most replacements are due to mechanical failure; creosote treatment delays the need for such replacements. Creosote appears to impart water repellency that lowers moisture content and reduces moisture-content cycling between wet and dry periods, especially while ties are exuding preservative (Hedley 1973). Over a period of years, however, this effect declines and water adsorption of creosote-treated ties approaches that of salt-treated ties.

Salt-treated ties are also reported to cause more corrosion of iron fasteners, and to be more conductive of electricity than creosoted ties, a matter of concern in railroads where electrical-signal systems are used.

Efforts to improve the weathering properties of salt-treated ties include a CCA emulsion to reduce rapid uptake of water (Belford and Nicholson 1968, 1969). The product reduced splitting of ties, performing in a manner comparable to a heavy oil treatment. The CCA addition is described as a solution of long-chain, petroleum-hydrocarbon fractions containing non-ionic surface-active agents and a light-petroleum fraction solvent that is self-dispersing in the CCA solution. After injection into wood, the emulsion is reported to break and the hydrophobic materials to be deposited on the inner surfaces of the cell cavities. Levi et al. (1970) reported that autoradiography revealed these hydrophobic materials in the earlywood rays of pine sapwood. The water repellents were effective to a depth of at least 1 inch.

Pretreatments with petroleum solvents have not improved the weathering characteristics of salt-treated ties (Hedley 1973). However, a light treatment of hardwood ties with a heavy oil or with creosote did (data from Hickson's Timber Products, Ltd. *in* Cooper 1976). Salt-treated ties subsequently treated to a 2.5 pcf retention with 3:1 diesel oil in creosote performed better in long-term service tests than ties conventionally treated with a 50:50 creosote-petroleum blend. Whether this double-treatment process is currently used commercially is unknown.

Laboratory and field tests indicate that 2.5 to 3.0 percent concentrations of pentachlorophenol in a heavy petroleum solvent protect hardwoods against decay as well as 50-50 blends of creosote and petroleum or coal tar (Baechler 1947a; Blew 1950; Olson et al. 1958). Long-term weathering characteristics of ties treated with this preservative need further study.

Retentions Needed to Protect Hardwoods.—The amount of chemical required to adequately protect wood from decay and insect damage varies with wood species, exposure conditions, and type of preservative. (See discussion under heading EFFICACY OF PRESERVATIVE TREATMENTS.) Table 10 is intended to give the reader some indication of equivalency—

with important reservations, as follows. There are only three heavy-duty preservatives (four if the relatively expensive copper naphthenate is included) suitable for soil-contact service: pentachlorophenol, CCA-ACA, and creosote. The other two listed in table 10 are recommended only for above-ground service. Acid copper chromate (ACC), however, is permitted for ground-contact service of non-critical items such as fence posts.

Of the preservatives listed in table 10, only creosote and CCA-ACA are suitable for softwoods and only creosote for hardwoods in marine (salt water) use. Retentions and assay zones for this type of service are (American Wood Preservers' Association 1977):

Preservative and species or species group	Retention in assay zone	Assay zone
	Pcf	*Inches*
Cresote		
Southern pine	20	0 to 3.0
Douglas-fir and oak	10	0 to 2.0
CCA-ACA		
Southern pine	2.5	0 to 0.5
	1.5	0.5 to 2.0
Douglas-fir	2.5	0 to 1.0

CCA and ACA are not recommended for hardwood marine piling.

Retention by hardwood lumber, timbers, and crossties is determined by gauge readings or weight gain rather than by assay. Only two species groups are covered by current standards of the American Wood-Preservers' Association: oak (white and red) and gum (sweetgum and black tupelo).

While assay zones are defined in standards for southern pine poles, these definitions have no application to hardwood poles; hardwood poles are not used in the United States and no standards have been written for them.

New Preservatives and Preservative Systems

Other preservative systems, or modifications of existing ones, are being developed in response to the increasing cost of oil-borne preservatives and their petroleum solvents. Concern about environmental restrictions that may be imposed on the four major preservatives has further expedited the search for new ones with low mammalian toxicity which meet requirements of economy and effectiveness.

An oil-water-emulsion solvent system for pentachlorophenol that significantly reduces petroleum requirements has been developed. Initial test results of this new solvent system are promising[3]. Alkylammonium compounds developed in New Zealand are being studied for possible use in the United States. They have proven acceptable for above-ground use and are being tested for ground-contact service. A water-solubilized form of copper-8-quinolinolate appears to have promise for use in above-ground applications.

Preservative systems whose toxic mechanisms are operative outside the body of the invading organism have been investigated. The use of chelating agents to inactivate the micronutrients required by fungi for growth was first suggested by Zentmyer (1944) and tested against wood-decay fungi by Baechler (1947b) and Thompson (1964a). Success of this method depends upon inactivation of the trace elements in wood, as well as those from other sources, such as the soil, to which the fungus has access. Hence, it does not work. This is likewise true—for the same reason—of attempts to dethiaminize wood and hence deny to fungi this essential growth factor (Gjovik and Baechler 1968). Efforts to treat wood with materials that chemically inhibit the cellulase enzymes secreted by fungal hyphae, thus preventing decay from occurring, have also failed (Reese and Mandels 1957; Thompson 1965).

Table 10.—*Retentions of six classes of preservatives in assay zone for approximately equivalent protection of hardwoods*

Preservative	Service above ground	Service in soil contact
	-----*retention, pounds/cu ft*----	
Creosote[2]	6.00	8.00
Pentachlorophenol[3]	.25	.40
Chromated copper arsenate (CCA)[4] or ammoniacal copper arsenate (ACA)[4]	.25	.40
Copper naphthenate[5]	.40	.75
Acid copper chromate (ACC)[4]	.25	.50[6]
Chromated zinc chloride (CZC)[3]	.45	not recommended

[1]Protection of piling against marine organisms requires highe preservative retentions of creosote than those shown. None o the other preservatives is recommended for use in salt-wate exposure of hardwoods.

[2]Retention of whole creosote.

[3]Retention of anhydrous chemical.

[4]Retention of anhydrous chemical, oxide basis.

[5]Retention of copper, as metal.

[6]Recommended only for non-critical items in soil content, e.g. for fence posts.

METHODS OF PRESERVATIVE TREATMENT

Wood may be preservative treated by either pressure or non-pressure processes. Pressure impregnations involve the application of 50 psi pressure or more in large cylinders to force preservative liquid into the wood (figs. 4 and 5). Pressure treatments account for

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[3]Hatcher, D. 1979. Private communication.

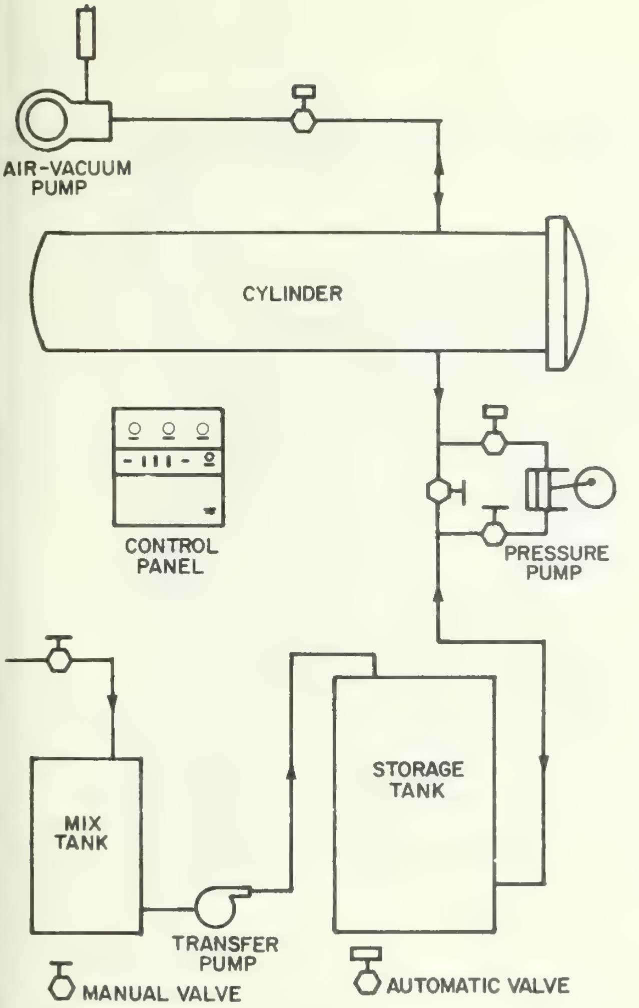

Figure 4.—*Schematic diagram of piping, storage tanks, and treating cylinder (retort) for pressure-impregnating wood with preservative. The air vacuum pump permits the cylinder to be evacuated before admission of the preservative, during a drying cycle (boiling under vacuum), or following the pressure cycle and drainage of the preservative.*

more than 95 percent of the wood treated in the United States by all processes except brush, dip, and spray. The remainder is treated by various non-pressure processes that include thermal, diffusion, cold soak, and vacuum methods. Brush, dip, and spray methods are also used, but not for material intended for ground-contact service. Products treated by these latter methods include millwork, which alone accounts for 60 million cubic feet of wood[2].

Pressure Processes

Pressure processes are differentiated by the air pressure applied to the wood before impregnation with a preservative. The full-cell process employs an initial vacuum to obtain maximum retention of preservative (fig. 6). The empty-cell processes employ either atmospheric pressure (Lowry Process) or higher air pressures of 15-75 psi (Rueping Process) (fig. 7). Hydrostatic or pneumatic pressures of 50 to 200 psi are imposed on the system and maintained until the desired gross injection of preservative has been achieved. The pressure is then gradually returned to atmospheric level and the excess preservative returned to storage. The treated wood may be subjected to a final vacuum or steaming and vacuum of short duration to remove surplus preservative from the surface of the wood.

The treating process and conditions employed and the preservative retention are determined by the species of wood, the preservative used, and the service conditions to which the wood will be exposed. Refractory species, such as white oak, require higher treating pressures than permeable species like southern pine. Treating temperatures of 210°F to 239°F are used to reduce the viscosity of creosote, while those used with pentachlorophenol-hydrocarbon solutions range from ambient to 220°F, depending upon the hydrocarbon (heavy petroleum, mineral spirits, or liquified petroleum gas). Target adsorption determines which of the two pressure processes is used. Products such as marine piling must be treated by the full-cell process to obtain the high preservative retention of 20 pcf required. Water-borne preservatives also are applied by the full-cell process. The empty-cell process is used for products, such as utility and construction poles, for which retentions of 6 to 12 pcf are needed.

Modifications of the basic pressure treating process that involve different pressure and temperature regimes from those in common usage have been explored at pilot-scale levels. Pressures in the range of 600 to over 2,000 psi have been used in these studies in an effort to improve the treatment quality achieved with refractory hardwood species (Walters and Guiher 1970; Akhtar and Walters 1974) and to obtain maximum loading of monomers in stabilization treatments (Rosen 1975a). In addition, oscillating pressure and vacuum treatments and other variations have been studied for possible beneficial effect on treatment quality. Some innovations and special applications of pressure methods that have been tried—some successfully and some not—are discussed in following sections.

Solvent Recovery Processes.—Two relatively new pressure treating processes receiving commercial application are unique in that the preservative—pentachlorophenol—is injected into wood in volatile solvents which are subsequently recovered and reused. The more commercially successful of these is the "Cellon Process" developed by Koppers Company, Inc., that employs liquified petroleum gas as the solvent. The other process was developed by Dow Chemical Company and uses methylene chloride as the solvent. The treating cycles employed with both processes are similar to those used with pentachlorophenol in oil,

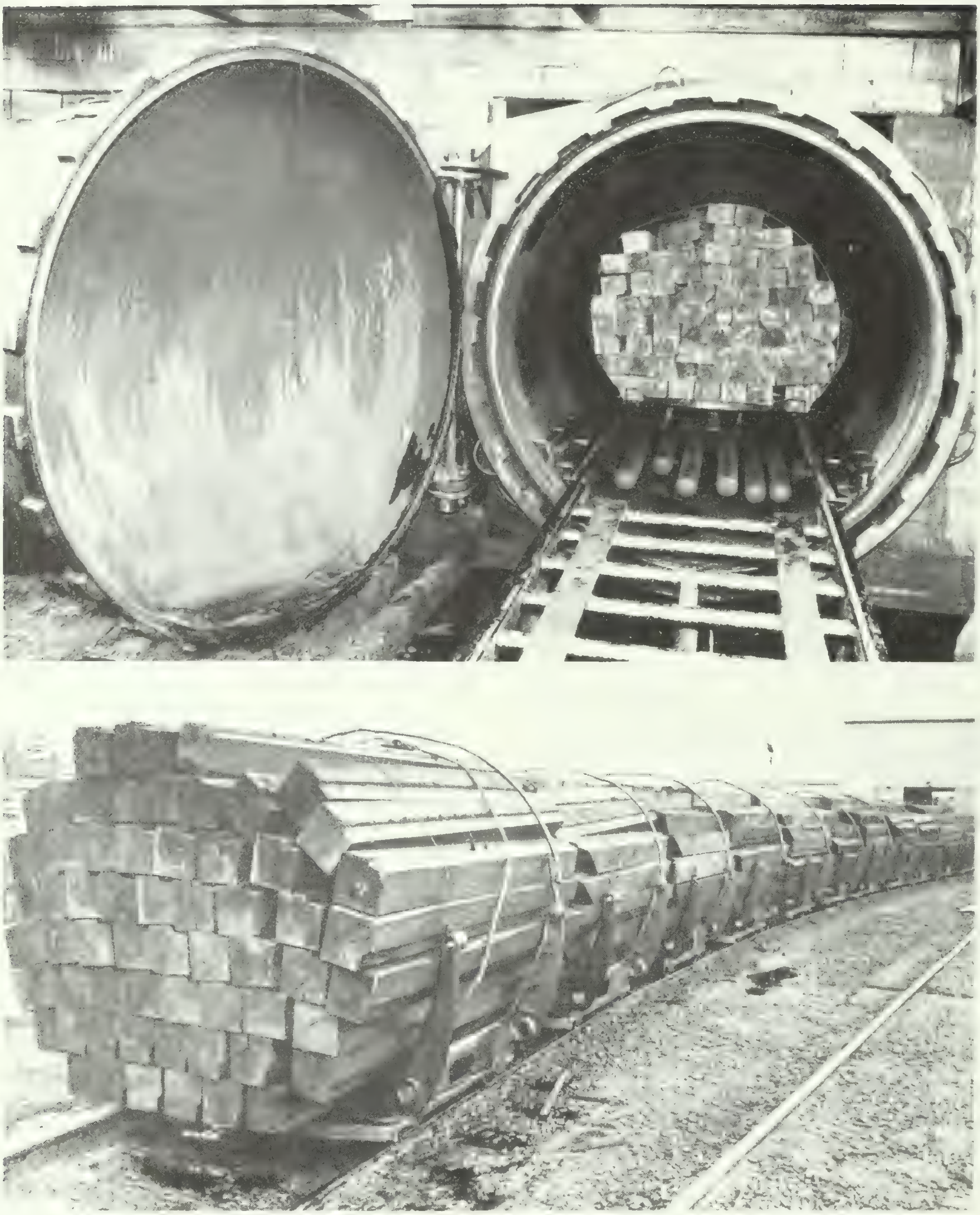

Figure 5.—*Commercial operation for pressure-impregnating wood with preservative. (Top) Frontal view of 7- by 130-foot retort ready for discharge. (Bottom) Freshly pulled charge of creosote-treated hardwood crossties.*

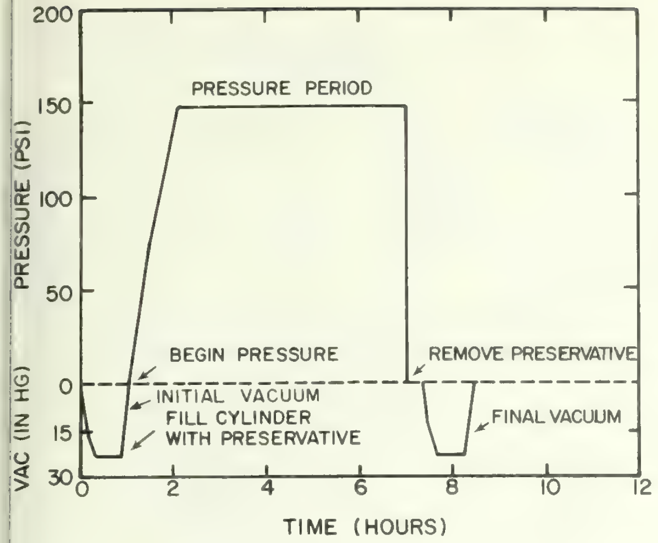

Figure 6.—*Schematic showing the treating schedule for full-cell treatment.*

except that each has a solvent-recovery step following the pressure period. Wood treated by these processes retains its natural appearance and can be used where cleanliness and paintability are requirements. Neither method is used to any significant extent in the treatment of hardwoods.

Modified Empty-Cell Process.—A modified empty-cell treatment for use with CCA-type preservatives was developed by Kelso[4] as an alternative to the conventional full-cell treatment currently used by industry (fig. 8). Impregnation is accomplished by either the Rueping or Lowry processes. After the desired gross adsorption is achieved, the preservative is removed from the retort while simultaneously maintaining a pressure such that kickback of the preservative solution in the wood is prevented. Fixation of the preservative is accelerated *in situ* by admitting to the retort either water or steam and maintaining a temperature of about 220°F for a period of 1 to 4 hours, depending upon the size of the items in the charge. Upon completion of the fixation period, the pressure is reduced and kickout of the spent preservative solution allowed to occur. Moisture contents of stock treated by this process are typically only one-third that of wood treated by the conventional full-cell process. In addition, the process permits rapid sequential treatment of wood with dyes, water repellents, stabilizing chemicals, or other preservatives.

Oscillating-Pressure Techniques.—Efforts to improve treatment quality of refractory species by sequential changes in pressure have generally been unsuccessful. An oscillating pressure technique, in which pressure (120 psi) and vacuum (28 inches of mercury) were alternated repeatedly throughout a 22-hour impregnation cycle, did not improve retention and penetration in the heartwood of either hardwoods or softwoods (Blew et al. 1961). However, the process did improve sapwood treatment in sweetgum over that achieved by conventional treating processes.

Work by McQuire (1964) indicates that the oscillating pressure method may have potential in the treatment of green wood, but not for dry wood. Its efficacy with green wood is attributed to exchange of wood water and preservative during the alternate pressure and vacuum cycles and to an increasing flow rate which accompanies the removal of air bubbles from the pores during the vacuum phase (Nicholas and Siau 1973).

Use of Shock Waves and Ultrasonics.—Low frequency shock waves and ultrasonics were investigated to improve the treatment of wood. The use of shock waves, induced by striking the retort with a hammer, produced some improvement in the treatment of oak crossties (Burdell and Barnett 1969). This effect was attributed to deaspiration of pits and dislodging of air bubbles from the pores (Nicholas and Siau 1973). Penetration of refractory woods was not improved.

The use of ultrasonic waves while wood is immersed in a liquid at atmospheric pressure can result in a significant increase in adsorption of certain liquids (Borkin and Corbett 1970). The improvement mechanism is thought to be the formation and removal of minute air bubbles, resulting in the removal of air-liquid interfaces which block penetration of liquids.

Pressure Treatment of Crossties.—Although hardwoods, in the form of crossties, constitute a large fraction of the total volume of wood pressure treated annually in the United States, treatment-response data for individual species are limited. Current standards (American Wood Preservers' Association 1980a) for the treatment of hardwood crossties with creosote and its solutions specify the following minimum retention and penetration values for the species groups shows:

Species group	Retention	Penetration
	Pounds/cu ft	
Red oak	8	65 percent of annual rings
White oak	Refusal	95 percent of sapwood
Sweetgum and black tupelo	10	1.5 inches or 75 percent of sapwood
Beech, birch, maple	7	85 percent of sapwood
Ash, hickory	Refusal	95 percent of sapwood

Determination of actual retention values by assay is not part of this standard. Hence, data are usually available only for cylinder charges, based on calculated retentions and, where required, checks of penetration on sample pieces.

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[4] W. C. Kelso, Jr. Unpublished data. Mississippi For. Prod. Lab., Mississippi State Univ., Mississippi State.

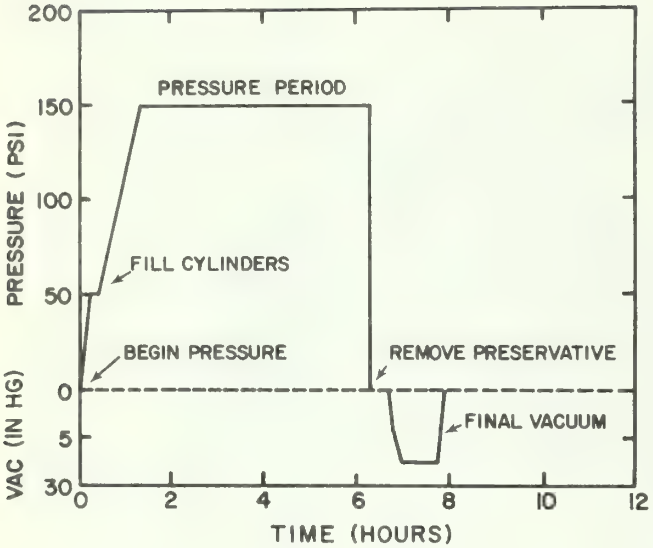

Figure 7.—*Schematic showing the treating schedule for empty-cell treatment.*

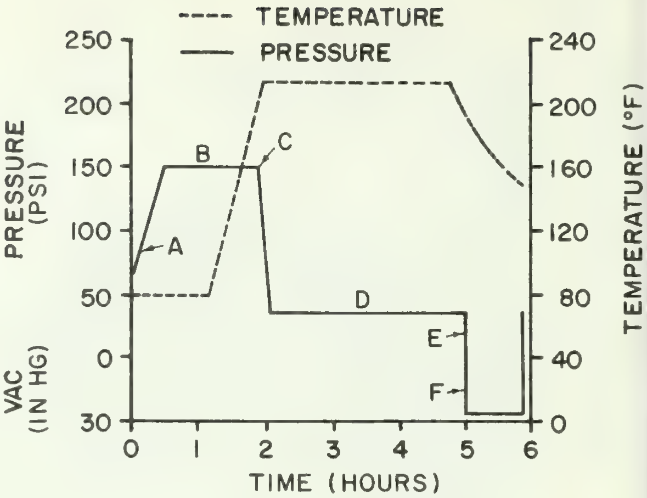

Figure 8.—*Treating cycle used to treat southern pine pole se tions with CCA by a modified empty-cell proces (A) Initial air pressure and fill cylinder. (B) Pressur period. (D) Maintain pressure sufficient to preven loss of preservative from wood during fixation perio (E) Release pressure and recover kickback from woo (F) Final vacuum.*

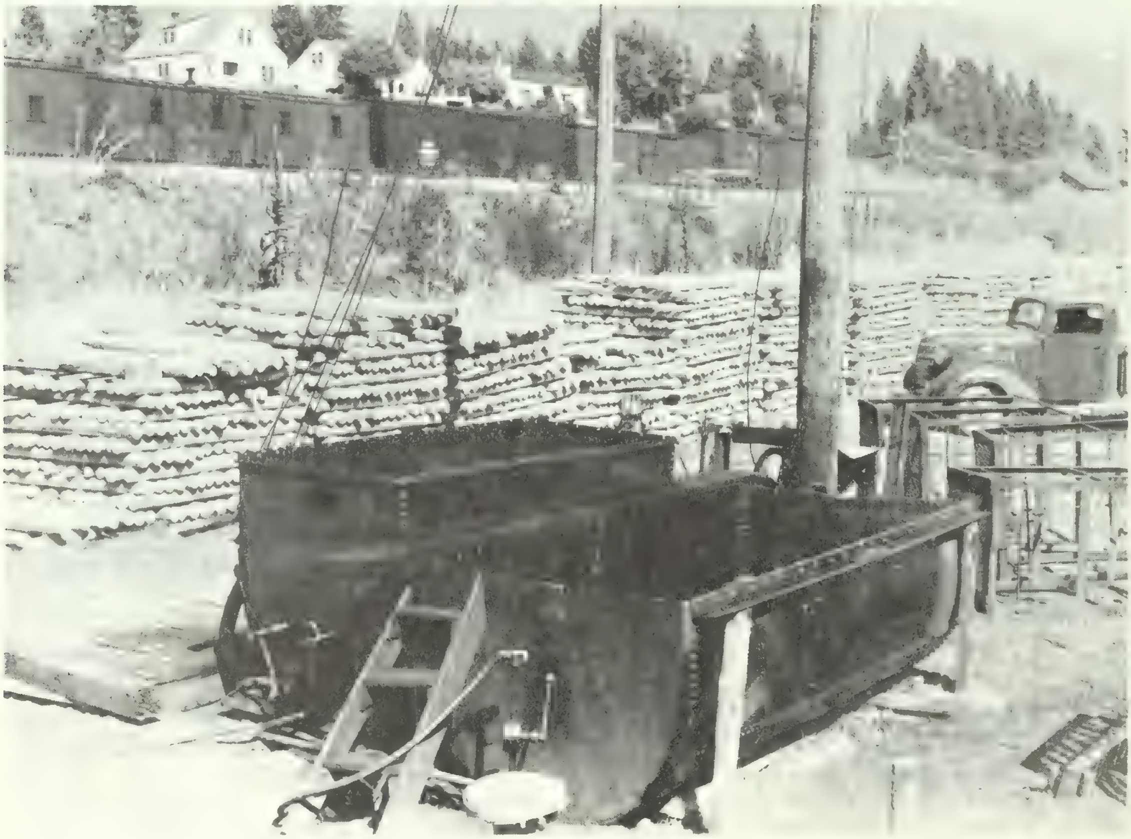

Figure 9.—*Typical thermal treating plant. A boiler (not shown in photo) supplies steam to heat coils in the bottom of the tank at left. The tank at right is for cool preservative. Wood is transferred between tanks manually or by hoist mounted on adjacent pole.*

Table 11.—*Summary of creosote penetration and retention in hickory crossties by method of seasoning (Taras and Hudson 1959)*

Investigator	Seasoning method and time	Moisture content at treatment	Penetration	Retention
		percent	*inches*	*pounds/cu ft*
Hudson (1954)	Air drying (6 months)	34	1.0	4.8
Shinn (1955)	Air drying (15 months)	26	1.3	6.0
Vaughan[1]	Controlled air seasoning[2] (11 days)	43	1.3	6.0
Hudson (1951)	Vapor drying (12 hours)	35	1.7	6.4
Collister (1955)	Vapor drying (15 hours)	20	1.8	11.7
Diechman (1954)[3]	Vapor drying (15 hours)	32	2.2	9.0
Huffman (1958)	Vapor drying (3 days)	32-47	2.2	5.5

[1] Vaughan, J. A. 1954. The use of hickory for railroad crossties. Southern Wood Preserving Company Rep., File 11-A-5 HTS.

[2] Process for slow drying of poles and crossties. See Vaughan (1954, 1955).

[3] Diechman, M. W. 1954. Vapor drying and treatment of hickory crossties. Unpublished report, Taylor-Colquitt Company.

Federal specification TTW-571 is more explicit and provides that, for species not covered either in that document or in AWPA specifications, penetration of heartwood faces will be not less than 0.4 inch in lumber and 0.5 inch in timbers.

The relative abundance and favorable mechanical properties of hickory have prompted extensive research on its suitability for crossties. Its reputation for excessive checking and splitting and for being difficult to treat has concentrated much research on seasoning and treating properties (Taras and Hudson 1959).

Investigators generally agree that moisture content of hickory should be between 20 and 40 percent for adequate retention and penetration (table 11). Seasoning and treating properties of hickory appear to be similar to those of the red oaks. Huffman (1958) found that degrade of hickory ties during seasoning in some studies was no worse—and in some instances was less—than that for other dense species such as the oaks.

In contrast, uneven distribution of creosote in pressure-treated, 4-inch-square hickory timbers was reported by Lund (1966). Despite an average retention of 9.6 pcf, only 46 percent of the treated stock had commercially acceptable penetration. Eighty-five percent had penetration skips, mostly associated with mineral streaks at worm galleries and other injuries. Skips present following treatment were not reduced by preservative migration over a 5-year period.

Pressure Treatment of Posts.—While the literature on treatment of hardwood posts deals principally with non-pressure treatments, some retention values for pressure treatments of post-size material with creosote by the empty-cell process are available (table 12). No penetration data accompanied these values. The retention values for all species met or exceeded the minimum recommended retention for softwood posts (American Wood Preservers' Association 1980b); there are no standards for hardwood posts.

Cook (1978) pressure treated 22 species of hardwood (table 13) with pentachlorophenol in a petroleum solvent conforming to P-9, Type A (American Wood-Preservers' Association 1977) by an empty-cell process with a maximum pressure of 100 psi for 50 minutes. This treatment regime is very mild for hardwoods, in terms of both pressure and duration. Retentions in the outer 0.25 inch varied greatly, the soft hardwoods generally having greatest retentions in this zone. In only six species was penetration deep enough to estimate retention in the 0.25- to 1.0-inch zone.

Non-Pressure Processes

Non-pressure processes are employed both commercially and by individuals for farm and ranch uses. Conditioning of stock is usually by air-drying and for most purposes the wood must be seasoned to a moisture content of 30 percent or less prior to treatment. Diffusion-type treatments are applied to unseasoned wood. Thermal and cold-soak treatments are the non-pressure processes most frequently employed commercially. In both, the wood is exposed to the preservative in an open vessel.

Thermal Process.—In this process wood is immersed in hot preservative for a fixed period of time—usually

4 to 12 hours—followed by exposure to preservative at ambient conditions (fig. 9). Variations of this treatment include use of separate vessels for the hot and cold baths and using a single vessel to which hot or cold preservative can be pumped as appropriate. A few small operators in the South leave the stock in the hot tank so that wood and preservative cool together.

Pentachlorophenol in petroleum is the preservative normally used with the thermal process, but other preservatives, notably creosote, may also be used. In the past this process was used extensively because creosote, the principal preservative, was too viscous at ambient temperature. Availability of pentachlorophenol and copper naphthenate which can be applied by cold-soaking has reduced use of the thermal process; thus the data base for thermal treatment is limited. Retentions of creosote and 5-percent pentachlorophenol solution achieved with thermal and cold-soak treatments, respectively, are shown in table 14. The numerous sources of these data do not permit more than a general interpretation of results. Retentions obtained with the thermal process for creosote are generally higher than those for pentachlorophenol obtained by cold soaking. By both processes the soft hardwoods appear to be more easily treated than the dense hardwoods.

Putnam (1947) investigated the treatability of bottomland hardwoods in Mississippi, using residence times of 1½ to 2 hours in the hot bath and 15 to 60 minutes in the cold bath. Satisfactory treatments were obtained in posts of ash, cypress (*Taxodium distichum* (L.) Rich.), elm, hackberry, honeylocust, maple, overcup oak, water oak, pin oak, pecan, persimmon, sweetgum, and willow. Results with cottonwood were unsatisfactory.

Cold-Soaking.—This process involves simply placing wood in a vessel, covering it with preservative solution, and allowing it to soak until it adsorbs the appropriate amount of preservative, as determined by weight gains (fig. 10). It has been used extensively to treat fence posts and lumber for farm and ranch uses, and in some research tests. The process is normally used with pentachlorophenol solutions, but other preservatives, including water-borne salts, may also be used.

Table 12.—*Creosote retentions in hardwood posts treated by a pressure process (Kulp 1961)*

Species	Retention
	pounds/cu ft
Elm, American	9.1
Hickory	9.7
Maple	6.5
Oak, black	6.6
Oak, blackjack	7.9
Oak, northern red	5.9
Oak, white	6.0
Sweetgum	9.7

Table 13.—*Retentions of pentachlorophenol by hardwood post sections treated by a pressure process*[1] *(Cook 1978)*

Species	Retention of pentachlorophenol	
	0.25 inch	0.25-1.0 inch
	pounds/cu ft	
1. Sweetbay	0.56	...
2. Black Tupelo	.52	0.17
3. Yellow-poplar	.50	...
4. Sweetgum	.48	.23
5. Red maple	.37	...
6. American elm	.36	...
7. Post oak	.34	.06
8. Scarlet oak	.26	...
9. Shumard oak	.26	...
10. Black oak	.26	...
11. Green ash	.26	...
12. Hackberry	.26	...
13. Blackjack oak	.26	...
14. Cherrybark oak	.25	
15. Water oak	.23	...
16. Hickory, true	.22	.02
17. White ash	.22	...
18. Winged elm	.21	...
19. Southern red oak	.20	.05
20. Northern red oak	.20	...
21. White oak	.18	.05
22. Laurel oak	.17	...

[1] Because treatments were very mild, these values reflect relative difficulty of treatment rather than typical effective treatments for these species.

Preservative retentions obtained by cold soaking vary widely among species and with moisture content. Some control over retention by permeable species can be exercised by adjusting the period of immersion. Retentions achieved with refractory species usually represent a compromise between the adsorption desired and the maximum feasible soaking period. Retention of 6 pcf of 5 percent pentachlorophenol solutions, the minimum allowed for ground-contact service by the American Wood Preservers' Association (1980b), is seldom achieved in oak and certain other species by non-pressure treatments. Retentions after cold soaking obtained in selected studies are summarized in table 15 for 16 of the hardwood species commonly found growing on southern pine sites.

The retention data presented are for pentachlorophenol in petroleum solvents and represent many different studies. Pretreatment moisture content and treating solution temperature are unknown. Differences among species are apparent. Retentions for the oaks, elm, and hickory were generally less than 5.0 pcf while those for the soft hardwoods—red maple, sweetgum, black tupelo, and yellow-poplar—were generally greater than 5.0 pcf. These groupings agree reasonably well with the categories in tables 3 and 4 developed by Teesdale and MacLean (1918) and Siau et al. (1978), respectively. There is a tendency for the retention values to vary

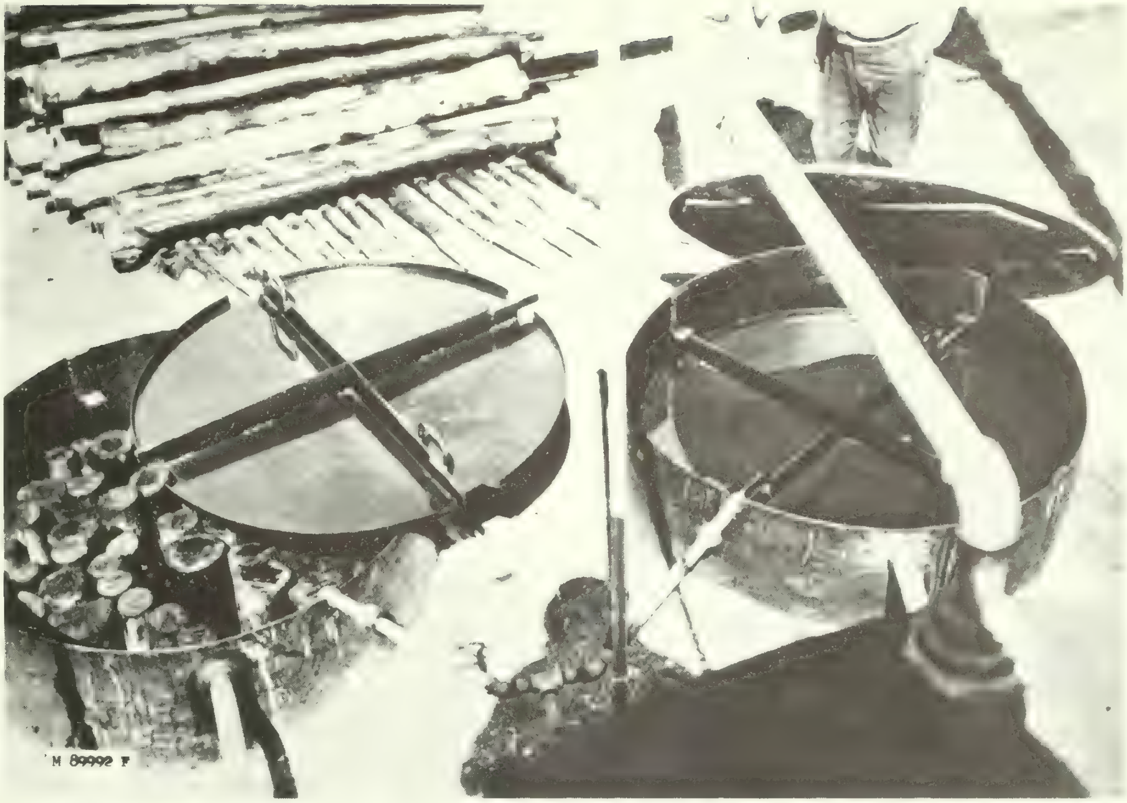

Figure 10.—*Preservative treating plant equipped to employ the cold-soaking process. Tank tops are equipped with latch mechanism to hold wood submerged. Piping arrangement maintains preservative level desired in tanks. Wood is charged manually or with the aid of a hoist.*

Table 14.—*Retention of creosote applied by the thermal process and 5 percent pentachlorophenol by cold-soak treatments in hardwood fence posts.* (Data from Kulp 1966; Gjovik and Davidson 1975.)

Species	Retention	
	Thermal	Cold soak
	pounds/cu ft	
Ash, green	8.9-11.9	6.1 (2)[1]
Ash, white (butts only)	5.1[2]	......
Basswood	6.1[2]	2.4[2]
Beech	8.5	......
Elm, American	8.0	......
Hackberry	8.0-12.7	3.5 (5)
Maple, red	8.2	7.0 (2.6)
Oak, blackjack	4.1	4.5 (8.1)
Oak, overcup	6.1-9.5	5.2 (5)
Oak, northern red	2.4	4.2 (2.8)
Oak, water	8.4-9.6	......
Oak, white	2.4	......
Pecan, bitter	6.0-8.9	5.2 (5)
Persimmon	7.9	3.9 (2)
Sweetgum	9.9-11.0	5.6 (2.7)
Tupelo, water	8.6	5.8 (4.5)
Tupelo, black	7.2	
Willow, black	8.4	3.8 (2)
Cottonwood	10.0	6.3 (4)

[1] Numbers in parentheses are treating times in days.
[2] Pounds per post.

inversely with specific gravity. Green ash is an exception in all three tables, its retention of preservative being greater than predicted by its specific gravity.

Diffusion Treatments.—These processes apply waterborne salt formulations to unseasoned wood by diffusion. In the traditional application, the treating solution contains a single salt of a metal, such as copper sulfate or zinc chloride. Such treatments have generally been unsatisfactory for exterior exposure because of rapid loss of the preservative by leaching.

In a variation called **double diffusion** (Baechler et al. 1959), the wood is soaked successively in two different aqueous inorganic salt solutions. The two components react within the wood to form relatively insoluble, toxic precipitates. A retention of 0.4 pcf by double diffusion is adequate for soil-contact service and is not subject to leaching. One pcf of leachable salts (e.g., zinc chloride) is more than adequate for protection, but an excess is needed to compensate for leaching.

Another diffusion process studied extensively in the South (Anonymous 1960) employs a solution of a single salt, such as zinc chloride, and green, unpeeled posts. The posts are placed vertically in a shallow pail containing the quantity of solution calculated to provide a net retention of about 1 pcf of the salt in the posts (fig. 10). The ends of the posts are reversed when about one-half of the solution has been adsorbed and the process is continued until the solution is adsorbed. This process provides somewhat better protection for wood in exterior service than conventional diffusion treatments with zinc chloride because the bark inhibits leaching of the preservative as long as it remains intact.

Yet another variation of the diffusion process employs as the preservative a water-soluble salt or salt formulation in dry or paste form. The preservative is spread over the surface of unseasoned, peeled wood, which is then dead-piled and covered to reduce loss of moisture. The preservative diffuses into the wood during a treating period that ranges from a few days to more than 2 weeks, depending upon the product involved.

Diffusion treatments have potential in the treatment of hardwoods because retentions comparable to those obtained by pressure processes are attainable. The double-diffusion process, in particular, is promising because of the long-term protection afforded by the heavy metal complexes formed in the wood.

In studies conducted by Baechler et al. (1959), fence posts cut from several hardwood species were soaked first in a solution of zinc sulfate and arsenic acid and then in a solution of sodium chromate. Exposure periods were 1, 2, and 3 days in each solution. Total retentions of anhydrous salt by species for each exposure period are shown below (Vick et al. 1967):

Species	Retention		
	1 day	2 days	3 days
	-----------	*Pounds/cu ft*	-----------
Yellow-poplar	1.99	2.97	3.15
Sweetgum	1.93	2.41	2.88
White oak	1.27	1.50	2.26
Red oak	1.04	1.57	2.07
Hickory	.39	.70	1.03

Retentions for cypress and southern pine, which were also included in the study, were of the same order of magnitude as those for the hardwoods. Heating the first solution accelerated chemical uptake and, except for white oak (1.69 pcf), red oak (1.60 pcf), and hickory (0.78 pcf), the adsorption was higher than would be desired in practice.

In other work reported by Baechler and Roth (1964), the double-diffusion treatment with copper sulfate and sodium arsenate provided good retention and adequate to excellent penetration in birch, maple, basswood, California blue oak, and bluegum (*Eucalyptus globulus* Labill.) when these species were soaked one day in each of the two solutions. They concluded that this process seems to offer promise as a method of treating hardwoods. However, the authors emphasized that several investigators have shown that certain decay fungi frequently associated with decay of hardwoods are

Table 15.—*Preservative retention in hardwood posts treate by cold soaking in pentachlorophenol-petroleu solutions. (Data from Kulp 1966; Gjovik and Davi son 1975.)*

Species and treating period (days)	Retention
	pounds/cu f
Ash, green	
2	6.1
Elm, American	
2	3.2
4	3.2
5	2.5
Hackberry	
2	4.4
5	3.5
Hickory	
2	3.8
3.7	4.3
5	3.6
Maple, red	
0.5	2.5
1	5.4
2	5.8
2.2	5.7
3.5	9.5
Oak, black	
2	2.7
Oak, blackjack	
6.3	4.1
8.1	4.5
Oak, chestnut	
2	8.7
2.8	5.6
Oak, northern red	
2.8	2.6
4	4.4
Oak, post	
2	3.2
3	3.1
. . .	5.7
Oak, scarlet	
1.8	3.9
Oak, southern red	
2	5.9
. . .	4.8
Oak, white	
2	2.4
3.9	5.3
. . .	6.1
Sweetgum	
.25	5.0
1	5.7
2	5.1
3	6.0
4	4.5
6	7.2
Tupelo, black	
.2	7.4
.5	5.5
4	4.4
Yellow-poplar	
1	5.4
1.4	5.2
2	6.6
3	6.1
6	8.8

elatively resistant to inorganic preservatives. They urmised that chemical costs probably will be higher n treating hardwoods than in treating softwoods ecause of that fact.

Boone et al. (1976) found that penetration and etentions by aspen, soft maple, and red oak lumber vere generally not satisfactory when the conventional louble-diffusion process was used. However, a modified rocess, using a heated first bath followed by partial lrying, gave very good results. Retentions achieved in spen and maple exceeded those obtained by pressure reatment.

Modified double-diffusion processes were also used successfully by Johnson and Gonzales (1976) to treat several tropical hardwood species. The first solution was 10 percent copper sulfate and the second was 2.25 percent sodium arsenate and 3.25 percent sodium chromate for green material and 4.5 percent sodium arsenate and 6.5 percent sodium chromate for partially seasoned material. Retentions in the outer ½-inch of sawn material, principally sapwood, ranged from 0.14 to over 1.0 pcf, oxide basis, depending upon treatment schedule, species, and whether or not the specimens were incised. Retentions for all species were considered adequate to provide a high degree of protection for ground-contact service in the tropics. Similar results were obtained by Smith and Baechler (1961) in exploratory treatment studies of Hawaiian-grown fence posts. Promising results were obtained with silk oak (*Grevillea robusta* A. Cunn.), bluegum (*Eucalyptus globulus* Labill.), *Eucalyptus saligna* Sm., and *Eucalyptus robusta* Sm.). Skolmen (1962, 1971), however, treated these same species by double diffusion and reported only a marginal improvement in service life after 10 years of field testing in Hawaii.

Table 16.—*Preservative retention of inorganic salts by hardwood posts treated by diffusion processes. (Data from Kulp 1966; Gjovik and Davidson 1975; Baechler et al. 1959.)*

Species	Retention
	pounds/cu ft of anhydrous chemical
Elm	0.90
Hickory	.30[1]
	.70[1]
Maple, red	1.10
Oak, black	.65
Oak, blackjack	.70
Oak, post	.90
Oak, red	.89
	1.56[1]
Oak, white	.87
	1.70[1]
Sweetbay	.94
Sweetgum	1.14
	2.40
Tupelo, black	.89
	.52[1]
Yellow-poplar	1.43
	2.95

[1] Denotes double-diffusion treatments. All other values are for end diffusion.

Retention values for diffusion treatments of posts of some of the hardwood species that grow on southern pine sites are given in table 16. End diffusion values, being easily controlled to target retentions, tend to be lower than those for double diffusion. Posts treated by double diffusion tend to be overtreated. For both diffusion treatments, differences between refractory and permeable species are much less pronounced than with cold-soak and thermal treatments.

Behr (1964) treated American elm and aspen fence posts with anhydrous salts of copper sulfate, followed by disodium arsenate and/or sodium dichromate. The chemicals were applied under a plastic bandage to the debarked butt portion of green posts. Copper sulfate was applied first and left in contact for 6 to 13 days. Disodium arsenate and sodium dichromate were then applied to a wet paper towel inside the plastic bandage and the bandage rewrapped. The posts were then stored for several months. Distribution data for the preservative are given below; values have been converted to an oxide basis.

Species and assay zone	CuO	As_2O_5	CrO_3
		Pounds/cu ft	
American elm			
First ¼-inch	0.273	0.285	0.065
Second ¼-inch	.023	0	.004
Third ¼-inch	.004	0	0
Aspen			
First ¼-inch	.233	.396	.160
Second ¼-inch	.021	.003	.010
Third ¼-inch	.004	.001	0

Total retention was comparable to that attained by double-diffusion treatments, but most of the salts were concentrated in the outer ¼-inch of wood. Better results were achieved with aspen than with American elm. Behr recommended the procedure for groundline treatments of poles in service.

Dip, Brush, and Soak Treatments.—Extensive, long-term testing has shown that surface treatments applied by dipping, brushing, and spraying are efficacious in preventing deterioration of wood in above-ground exposure (Verrall 1961). Benefits vary with the preservative, treating method, solvent, presence or absence of a water repellent, wood finish, and exposure conditions. Two- to threefold increases in service life in above-ground, exterior exposure can be achieved by 3-minute dips with such preservatives as pentachlorophenol and copper naphthenate (2 percent copper) (Verrall 1953; 1959; 1961). The efficacy of such treatments for such items as pallets has also been verified (Nethercote et al. 1977).

Superficial treatments are also extensively used on unseasoned lumber to prevent stain, mold, and decay during seasoning (Lindgren 1930; Lindgren et al. 1932; Verrall and Scheffer 1949). Such treatments fall outside those activities normally considered to be wood preservation, and hence are not covered here. Likewise, protection of logs (Burkhardt and Wagner 1978) and chips (Bois et al. 1962; Silberman 1970; Eslyn 1973) in storage fall outside the subject matter considered.

EFFICACY OF PRESERVATIVE TREATMENTS

International Overview

Hardwood crossties constitute a significant fraction of the total volume of wood treated annually in the United States. Practically all crossties are treated with creosote (fig. 11). Almost a century of use has shown that a broad range of hardwood species, when properly treated with creosote solutions, perform satisfactorily in rail lines. Average service life of crossties ranges from 25 to 50 years, depending upon location; increasingly, tie failure is caused by factors unrelated to biological deterioration.

Performance data for hardwood products treated with preservatives other than creosote and for hardwoods in other ground-contact service is less extensive. Available data show an uneven pattern of performance ranging from good to bad, perhaps reflecting in part differences among species and among treating methods employed.

Definite information is generally lacking on t
specific organism responsible for failure. In gener
the white-rot fungi are the most important causes
decay in hardwoods. Some of these organisms (e.
Coriolus versicolor L. per Fr.) are much more tolera
of certain preservatives than are brown-rot organisr
(Thompson[5]; Gjovik[6]). Soft-rot fungi, which destr
wood despite preservative loadings that prevent dec
by *Basidiomycetes*, are increasingly recognized
important in decay of hardwoods in ground-conta
service.

In Europe and Australia hardwoods with hig
absorption and deep penetration of water-borne sal
are rapidly attacked by soft rot. Some authorit
recommend that salt-treated hardwoods not be us
in ground contact (Bergman 1977).

Noting that in tropical climates soft rot is the prima
cause of failure of treated wood in ground contac
especially hardwoods, Levy (1978) recommended u
of softwoods for poles where a choice is availabl
Soft-rot damage to improperly treated softwood pole
however, has also been reported (Henningsson et a
1976).

Greaves and Levy (1978) found evidence that lo
levels of CCA preservative in the fibers of hardwoo
may be responsible for poor performance. Eight of th

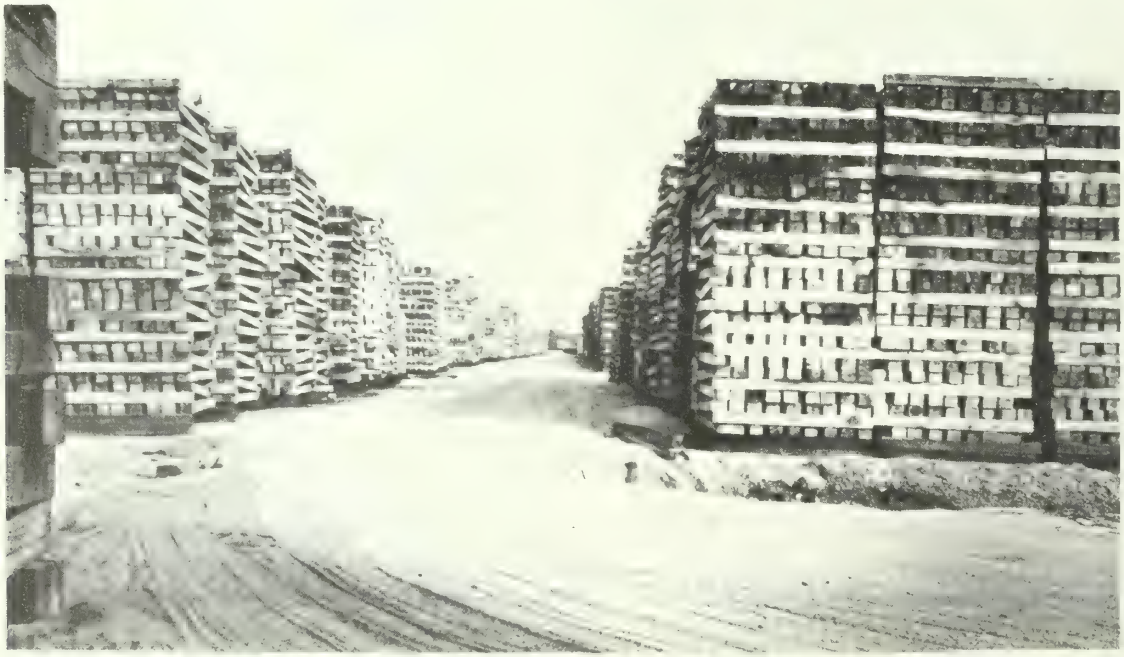

Figure 11.—*Hardwood crossties, shown here air-drying prior to treatment, account for about one-third of the 330 million cu ft of wood treated annually in the United States.*

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[5] Thompson, W. S. 1975. Unpublished data. Miss. For. Pro
Lab., Miss. State Univ., Mississipppi State, Miss.

[6] Gjovik, L. R. 1980. Personal communication with W. S. Thom
son.

10 hardwoods studied showed skewed CCA distribution patterns among vessels, fibers, and ray tissues. The pattern evident for CCA as a whole was also found individually for copper, chromium, and arsenic. Fibers contained much less CCA than either vessels or rays at all depths studied and ranged as low as 9 percent. The two species which showed uniform distribution performed satisfactorily in field tests.

On a different level, Dickinson et al. (1976) investigated the distribution of copper, chromium, and arsenic within individual wood cells where a normal CCA treatment protected softwood from both soft rot and *Basidiomycetes* and hardwood from *Basidiomycetes* only. Even a double treatment failed to protect the hardwood from soft rot. Elemental distribution of copper within tracheid and fiber walls, determined by electron-probe microanalysis, was as follows (data for chromium were similar):

Wall layer	Relative amount of copper	
	Softwood tracheids	Hardwood fibers
	X-rays emitted/second	
S_3	239	6.8
S_2	222	4.9
S_1	224	6.1
Middle lamella	183	5.4

Unlike the uniformly well treated tracheids, the fibers were poorly treated, with lowest quantities of preservative in the S_2 layer, where soft-rot fungi attack wood by forming distinctive cavities. Concentrations of copper, chromium, and arsenic were much higher in ray cells than in fibers.

Levy (1978) cited three reasons for the apparent preferential attack of hardwoods by soft rot.

1. High content of pentosan and other hemicelluloses easily utilized by soft rot.
2. Poor penetration of the fiber cell walls by the preservative.
3. High wall-to-lumen volume ratios in fiber cells resulting in low retention of preservative in fiber walls even at normally adequate retentions in pound/cu ft of wood.

Hulme and Butcher (1977), however, found no major differences in the gross or cellular distribution of CCA preservatives between hardwood and softwood specimens.

Tamblyn (1973) reported that in field trials at eight sites in Australia and New Guinea involving both eucalyptus and pine poles, and several preservatives, soft rot had seriously deteriorated the hardwood after only 6 to 8 years. He concluded that retentions of the best preservatives providing satisfactory protection in temperate climates are inadequate for some hardwoods in ground-contact service in the tropics.

By contrast Aston and Watson (1976) reported that in numerous parts of Africa creosote-treated eucalyptus has performed extremely well. They cited a power line near Pretoria, in which no poles failed during a 40-year period. They also reported similar results in Malaysia with *Shoria* sp treated with CCA. Purslow (1975) reported no failures in 44-year-old beech stakes treated with creosote or CCA and installed at Princes Risborough in England. In field trials in Scandanavia, however, beech and other hardwood species performed poorly when treated with either organic or inorganic preservatives (Henningsson 1974).

Investigations by Sorkhoh and Dickinson (1976) on the cause of early failure of treated hardwoods confirmed the findings of others (Tamblyn 1973; Henningsson et al. 1976; Levy and Greaves 1978; Greaves and Levy 1978), that soft-rot fungi are the causal organisms. Cavities were forming in the S_2 layer of the cell walls of six species within 3 days to 2 weeks following inocculation of samples. Treatment with CCA reduced neither the incidence of cavity formation nor the time required for their development. In similar studies Liese and Peters (1977) found that hardwood specimens treated with either copper or chromium were more heavily attacked by soft-rot fungi than those treated with both metals.

Those interested in performance records of salt-treated railroad ties outside the United States will find the following publications useful: Cooper (1976), Ellwood (1956), Krzyzewski (1973), Borup (1961), Hedley 1973).

Service Data in North America

North American service data for treated hardwoods are concerned mainly with crossties and fence posts. These two products represent distinctly different levels of exposure. Crossties placed on well ballasted roadbeds are subject to less biological hazard than fence posts in direct contact with soil (fig. 12). On the other hand, they are subjected to much higher levels of mechanical stress and may require replacement for causes unrelated to biological factors. Service data for the two products are thus not interchangeable.

Current estimates of service life of crossties in line are based on tests begun 30 to 50 years ago. Many preservatives then in actual or potential use have since been discontinued. For all practical purposes, only creosote and its coal-tar or petroleum solutions are employed in crosstie treatment today. A somewhat similar situation exists in the case of fence posts, although the time involved is usually shorter.

Crossties.—Average service lives of 50 years or more were reported by Blew (1963) for red oak and hard maple crossties treated with 5-12 pcf of creosote in tracks in Wisconsin compared to 6 to 10 years for untreated ties. Surprisingly, semi-refined paraffin oil

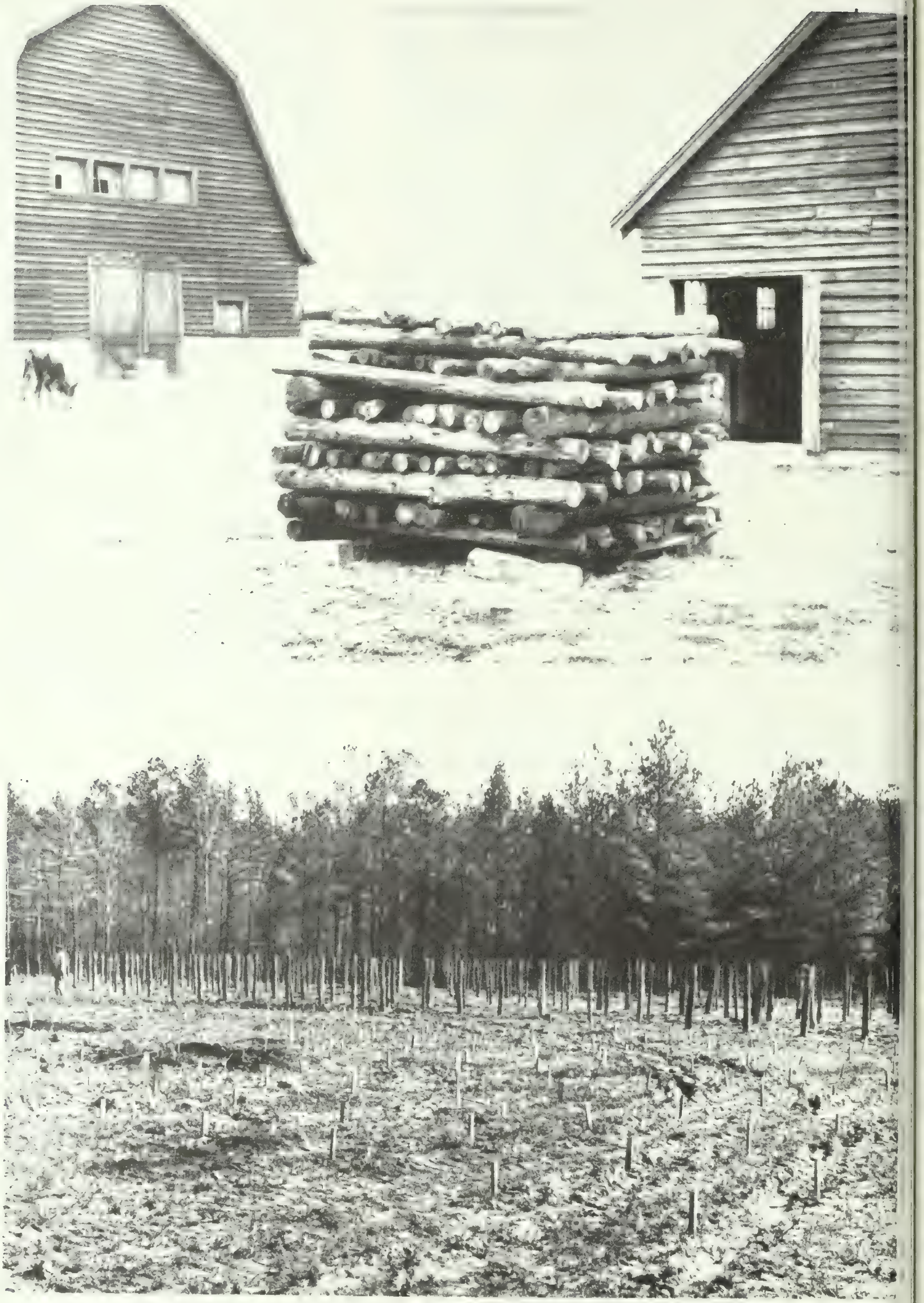

Figure 12.—*(Top) Peeled hardwood posts air drying prior to treatment. (Bottom) Treated posts installed during the years 1950-1954 near Starkville, Miss., to determine service life; some treated stakes are visible in the foreground.*

provided a service life for both species nearly as long as that for coal-tar creosote, as did a 20:80 emulsion of zinc chloride solution and creosote.

Blew attributed differences in average service life in two Wisconsin test tracks to the use of tie plates on some ties, better drainage, and less traffic at one site. In related studies, 50:50 blends of coal-tar creosote and wood-tar creosote at retentions of 7 to 10 pcf provided service lives of 23 to 44 years for slippery elm, red oak, white oak, cherry, and butternut crossties. Red oak ties treated with zinc chloride failed after an average service life of 17 years.

In other work, Blew (1966) found that service conditions as well as treatments affect the life of oak crossties. Average service life in Maryland for red oak and white oak crossties representing a variety of preservatives was 20 to 34 years and 21 to 31 years, respectively. Red oak ties treated to retentions of 8 to 10 pcf with creosote remained serviceable for about 34, 33, 21, and 19 years in Ohio, Pennsylvania, Texas, and Arkansas, respectively.

Reports of tie service life in Northern Pacific Railroad show that red oak ties treated either with straight creosote or a 50:50 creosote-petroleum blend have a service life throughout the system of 30 to 50 years (Radkey 1960). Mechanical failure was a contributing factor in the replacement of over 50 percent of these ties.

A comprehensive test of crossties in track has been underway in Canada for many years. Forty-year test data reported by Krzyzewski (1969) are summarized in table 17 by species and type of preservative treatment. It is of interest in this table that brush treatments with Osmolit (sodium fluoride and dinitrophenol) and Osmotite pastes (sodium fluoride, dinitrophenol and chromium salt) performed about as well as pressure treatments with Boliden salt or pentachlorophenol in petroleum. Only about 25 percent of all failures resulted from biological deterioration. Blew (1963, 1966) found that rail plates greatly reduced mechanical failure.

The service life of properly treated hickory ties has been shown to be equal to that of other more widely used tie species. Taras and Hudson (1959) summarized data from several studies which indicate a service life for hickory ties of 25 to 35 years. This range is very close to the estimated service life of 31 years for red oak ties included in the same track.

Bescher (1977) summarized available data on the life of creosoted crossties in mainline tracks. Tests beginning in 1909 and 1910 by the Chicago, Burlington, and Quincy Railroad showed that service life varied from 25 to 35 years, except for ash, which had only a 20-year life. Beech, sycamore, elm, red oaks, sweetgum, and black tupelo all had service lives averaging 30 to 35 years. Birch, cottonwood, hickory, pine, hard and soft maple, and white oak had 25- to 30-year service life. Crosstie life also varied significantly according to the quality of track and ballast maintenance, and with severity of traffic; crossties in tracks of a midwestern railroad that traditionally made a profit and maintained its tracks had service lives varying from 25 to 60 years depending on the amount of traffic.

Tie life is longest in side and yard tracks (60-year average), intermediate in branch lines (about 30 to 35 years), and shortest on heavily used mainline tracks

Table 17.—*Service life of hardwood crossties in Canadian railways by species, preservative, and retention (Krzyzewski 1969)*

Species	Retention	Preservative	Average service life
	pounds/cu ft		*years*
Aspen	7.2	Creosote	32.9
Red oak	.26	Zinc-meta-arsenite	23.9
Beech	.20	Zinc-meta-arsenite	21.9
Hard maple	.31	Zinc-meta-arsenite	23.5
Yellow birch	.25	Zinc-meta-arsenite	22.5
White birch	.26	Zinc-meta-arsenite	21.7
Beech, hard maple, red oak	.43	Osmotite (brush treated)	21.2
Red oak, yellow birch, hard maple	.43	Osmolit (brush treated)	21.2
Yellow birch, hard maple, beech	5.3-8.8	70/30 creosote-coal tar	27.0-31.7+
Yellow birch	8.1	50/50 creosote-petroleum	21.0+
Aspen		70/30 creosote-coal tar	18.0+
Beech, birch, maple		Copper naphthenate	20.0+
Birch	.40	Pentachlorophenol	17-18+
Birch	.60	Boliden salt	16.7+
Maple	.60	Boliden salt	15.7+
Red oak	.60	Boliden salt	17.0+
Aspen	7	50/50 creosote-petroleum	15-16+
Yellow birch	.30	Pentachlorophenol	15+
Hard maple	.42	Pentachlorophenol	15+

(about 25 years—possibly 35 years); on curved portions of mainline tracks, crosstie life is shortest.

In the future crosstie life may be further extended by fabricating them from two or more pieces of wood smaller than 7 by 9 inches, thus permitting more complete penetration by preservatives. One such fabrication procedure now in limited commercial use calls for dowel-lamination (no glue required) of two pieces measuring 4.5 by 7 inches into a 7- by 9-inch assembly (Howe and Koch 1976). Such two-piece crossties are more readily treated than one-piece ties. Preservative penetration from the two-piece interface, nearly equal to that from the outside surfaces, should augment protection against decay.

Tschernitz et al. (1979) described the Press-Lam process for making crossties which embodies stored-heat glue-laminating of thick-sliced veneer (0.25 inch or more thick) using residual heat of the wood as removed from the veneer dryer. They found that creosote preservative treatment was adequate for all species and treating time was only about half that for solid wood crossties.

Fence Posts.—Many service-life data for treated hardwood posts are from field installations (fig. 12) made between 1940 and 1960 at Land Grant universities and by the United States Forest Service. They involved a great number of preservative materials, methods of application, species of woods, and exposure sites.

The variables of site and method of application have complicated interpretation of these data, making it difficult to reconcile inconsistencies in results. This problem is aggravated by the large number of researchers involved and resultant lack of uniformity in treating solutions, applications, and in interpretation of inspection results (Gjovik and Davidson 1975). It often is impossible after the fact to distinguish between procedural errors and differences that are site related.

The reports available cover a range of non-pressure treating methods. Among these, the cold-soak, hot-and-cold bath, and diffusion treatments were most frequently used, but superficial brush, spray, or dip applications of preservative are also well represented.

Treatments of selected hardwood species to retentions averaging between 6 and 12 pcf by cold-soak and hot-and-cold bath process have proved satisfactory. In a study reported on by Carpenter and Bouler (1962), 85 percent of ash, American elm, honeylocust, mixed oak, bitter pecan, and sweetgum posts treated by this process with coal-tar creosote were still serviceable after 19 years' exposure in Mississippi. Sixty-three to 68 percent of cottonwood, red maple, and hackberry, but only 15 percent of the willow posts were serviceable after the same period.

Retentions of 5 percent pentachlorophenol in fuel oil comparable to those obtained with coal-tar creosote were also obtained by the same authors using the hot-and-cold-bath process (Carpenter and Bouler 1962). After 13 years' exposure, 83 to 100 percent (average 94) of posts of nine hardwood species, representing both heartwood and sapwood, were serviceable. Results for sweetgum were poorest, with 59 percent serviceable after 13 years. After being pressure-treated with creosote to a retention of 12 pcf, cottonwood posts were 100 percent and sweetgum 89 percent serviceable after 23 years; with retentions of 6 pcf, however, only 42 percent of sweetgum and 8 percent of cottonwood posts were serviceable. Carpenter and Bouler (1962) also reported that soaking of black willow and cottonwood in chromated zinc chloride provided a service life of 7 to 10 years.

Among 398 hardwood posts included in a study reported on by Walters and Peterson (1965), at least 87 percent of the green ash, black cherry, shagbark hickory, black oak, and red oak were still serviceable 21 years following a cold-soak treatment in a 5 percent solution of pentachlorophenol in fuel oil.

Green, unpeeled posts treated by end-diffusion with an aqueous solution of zinc chloride protected pine and some hardwood species for over 20 years (Toole and Thompson 1973). Over 80 percent of red oak, post oak, sweetgum, and pine posts in certain size classes were still serviceable after 20 years of exposure in a test plot in Mississippi following end-diffusion treatments that yielded retention of about 1.0 pcf (Thompson 1954). Time of harvest had some effect on serviceability, with posts cut when dormant out-performing those cut during the growing season, a result attributed to retention of bark by fall- and winter-cut posts and consequent reduced leaching of preservative.

Verrall (1959) studied the protection afforded ammunition boxes by dipping in a 5 percent pentachlorophenol solution containing a water repellent. After 4.4 years' exposure near Gulfport, Miss., the decay ratings were 2.3, 3.0, and 2.3 for sapwood of yellow-poplar, sweetgum, and tupelo gum, respectively, on a scale where 0 = no decay and 5 = destroyed. The comparable rating for southern pine sapwood was 1.8. Untreated wood of all species had ratings of 4.8 to 5.0.

Scheffer (1953) tested several fungicides against common wood-decay fungi on oak and several other species, for possible use in bilgewater in boats. The order of effectiveness was: phenylmercuric acetate, sodium pentachlorophenate, 2, 4, 5-trichlorophenol, orthophenylphenol, pentachlorophenol, boric acid + sodium dichromate, and boric acid. All were effective, but orthophenylphenol and pentachlorophenol were recommended because of their low solubility, safety in use, and low cost.

Superficial treatments of pentachlorophenol in light solvent containing a water repellent were found by Scheffer and Browne (1954) to provide a high degree of protection to sweetgum blocks exposed to *Coriolus versicolor*. This work was later verified by other studies (Scheffer and Clark 1967).

Compilations of service-life data for posts are available from the following sources:

Gjovik and Davidson (1975)	Reports on over 800 combinations of preservatives, retention levels, treatment methods, species, and exposure sites.
American Wood Preservers' Association Proceedings	Reports of Committee U-5, Post Service Records: Annually through 1969.
Anonymous (1960)	Results of studies by members of Wood Preservation Council.
Krzyzewski and Spicer (1974)	Results of Canadian post studies, 34 years.
Krzyzewski and Sedziak (1975)	Performance of treated posts.

Service-life and treating data gleaned from the aforementioned sources are shown in table 18 for selected species. Service-life for untreated wood of the same species is included in table 19. Extension of service life by preservative treatment varied principally with the preservative used and exposure site. Zinc chloride, chromated zinc chloride, and other water-soluble, nonreactive formulations generally gave poorer results than creosote or the oil-borne preservatives. Exposure site greatly affected service-life with these light-duty preservatives. Red oak posts treated by end-diffusion had a service life of 21 years in Wisconsin, but only years in Mississippi. Retention of zinc chloride by the Mississippi posts at 0.95 pcf was 27 percent higher than that for the Wisconsin posts.

The double-diffusion process generally protected posts better than one-step diffusion. Service life of red oak, sweetgum, and hickory posts treated with zinc sulfate followed by arsenic acid + sodium chromate and exposed in Georgia ranged from 16 to 22 years and averaged almost 20 years (table 18). This is near the average service life of 23 years for pentachlorophenol-treated oak posts exposed in Mississippi and Alabama. Results are even better when copper sulfate replaces zinc sulfate in double-diffusion treatment Gjovik and Davidson 1979).

The performance of copper naphthenate-treated posts was generally inferior to that for posts treated with creosote and pentachlorophenol. For example, oak posts treated with this preservative and exposed in Tennessee and Mississippi failed after only 8 to 14 years. These results indicate that solution concentration—in terms of percent copper metal—was inadequate even though gross adsorption of solution was comparable to that for other preservatives. A retention of copper naphthenate equivalent to 0.40 pcf of copper metal is needed for long-term protection of wood[2]. The copper content of treating solutions used in the studies reported was usually about 0.5 percent, too low by a factor of about 10 to provide the desired copper retention when gross adsorption was typically 4 to 6 pcf.

Service life for oaks treated with creosote, mainly by the thermal process, ranged from 27 years in Mississippi (pcf = 8.4 to 9.2), 50 years in Missouri (pcf = 6 to 11), and 40 years in Wisconsin (pcf = 4.1). These high performances appear to reflect above average treatment quality rather than the superiority of the preservative. For any given retention, pressure and thermal treatments should provide better penetration of preservative than cold-soak treatments. This trend was also evident with species other than the oaks.

Species prone to develop deep checks or splits may decay faster than split-resistant species. There is some evidence that cottonwood and willow perform more poorly than could be anticipated based on preservative retention (Hopkins 1951;Furnival 1954), probably attributable to uneven distribution of preservative.

Sweetgum is the hardwood species that has received the most attention from researchers in establishing field tests of wood preservatives. Results of tests conducted by eight state agricultural experiment stations located within the natural range of this species are listed in table 20. These data show that the two-year natural service life of this species is increased by a factor of seven or more by perservative treatment with pentachlorophenol and copper naphthenate and by a factor of about three by treatment with zinc chloride.

EFFECTS OF TREATMENTS ON WOOD PROPERTIES

Some of the treatments to which wood is subjected during preserving and stabilization treatments adversely affect its mechanical properties. Certain preservatives are themselves reported to reduce wood strength as do incising and conditioning preparatory to preservative treatment. The beneficial effects of these operations—improved quality of preservative treatments and extended service life—usually outweigh the negative effects.

Most studies of the relationship between wood strength and processing operations deal with softwood species. There are some data for hardwoods, however, and much can be inferred about hardwoods from softwood studies.

Incising

Perrin (1978) concluded that incising probably has a negligible effect on the strength properties of large items such as poles and crossties. For timbers smaller than crossties, however, the results were mixed, as indicated for Douglas-fir in table 21.

Table 18.—*Service life of hardwood fence posts by species, treating method, preservative, and exposure site. (Data from Anonymous 1960; Kulp 1966; Gjovik and Davidson 1975.)*

Species and treatment method (and time, hours)	Preservative		Exposure state	Year installed	Service life
	Material	Retention			
		pounds/cu ft			*years*[1]
American elm					
Hot-and-cold bath	Creosote	11.1	Mississippi	1941	....
Cold-soaking (48)	Pentachlorophenol (10 percent)	3.2	Illinois	1942	20
Cold-soaking (120)	Pentachlorophenol	2.5	Mississippi	1953	14
Beech					
Hot-and-cold bath	Creosote	8.5	Maryland	1908	48
River birch					
Hot-and-cold bath	Creosote	....	Maryland	1908	30
Bitter pecan					
Hot-and-cold bath	Creosote	6.0-8.9[2]	Wisconsin	1941	18+
Hot-and-cold bath	Pentachlorophenol	4.3-6.7	Mississippi	1949	13
Cold-soaking	Pentachlorophenol	5.2	Mississippi	1953	21
Blackjack oak					
Pressure	Creosote	6-11	Missouri	1938	50+
Pressure	Zinc chloride	.84	Wisconsin	1938	34
Hot-and-cold bath	Creosote	4.1	Wisconsin	1938	40
Cold-soaking (105)	Pentachlorophenol	4.1	Tennessee	1949	....
Cold-soaking (195)	Pentachlorophenol	4.5	Tennessee	1949	....
Cold-soaking (47)	Copper naphthenate	4.4	Tennessee	1953	8
Cold-soaking (48)	Copper naphthenate	3.4	Tennessee	1953	12
Black willow					
Steeping	Chromated zinc chloride	....	Mississippi	1948	5
Steeping	Chromated zinc chloride	....	Mississippi	1947	10
Hot-and-cold bath	Creosote	8.4[2]	Mississippi	1941	17
Box elder					
Cold-soaking (120)	Pentachlorophenol	9.8	Mississippi	1953	18
Cedar elm					
Cold-soaking (120)	Pentachlorophenol	5.1	Mississippi	1953	26
Cottonwood					
Pressure	Creosote	6.0	Mississippi	1937	18
Pressure	Creosote	12.0	Mississippi	1937	....
Hot-and-cold bath	Creosote	12.2[3]	Minnesota	1909	30
Steeping	Sodium fluoride	.28	Montana	1926	9
Steeping	Sodium fluoride	.67	Montana	1926	13
Hackberry					
Hot-and-cold bath	Creosote	8-12	Mississippi	1941	23
Hot-and-cold bath	Pentachlorophenol	10-13	Mississippi	1948	17
Cold-soaking (120)	Pentachlorophenol	3.5	Mississippi	1953	11
Hickory					
Double diffusion	[4]	.20	Mississippi	1953	14
Cold-soaking (120)	Pentachlorophenol	3.6	Mississippi	1953	21
Double diffusion	[5]	.39	Georgia	1955	19
Double diffusion	[5]	1.0	Georgia	1955	19
Northern red oak					
Pressure	Creosote	5.8	Wisconsin	1960	....
Hot-and-cold bath	Creosote	....	Maryland	1908	36
End diffusion	Chromated zinc chloride	.75	Wisconsin	1946	21
Cold-soaking (8)	Pentachlorophenol	3.2	Wisconsin	1943	14
Cold-soaking (24)	Pentachlorophenol	3.5	Wisconsin	1943	20
Cold-soaking (48)	Pentachlorophenol	4.5	Wisconsin	1943	28
Cold-soaking (96)	Pentachlorophenol	5.8	Wisconsin	1943	36
Cold-soaking (168)	Pentachlorophenol	5.7	Wisconsin	1943	36
Cold-soaking	Pentachlorophenol	1.8[2]	Minnesota	......	33
Cold-soaking (66)	Pentachlorophenol	2.6	Illinois	1942	....
Overcup oak					
Hot-and-cold bath	Creosote	6.1-9.5[2]	Mississippi	1941	30+
Hot-and-cold bath	Pentachlorophenol	2.7-7.9[2]	Mississippi	1947	18
Post oak					
Cold-soaking (72)	Pentachlorophenol	4.2	Alabama	1948	23
Cold-soaking (46)	Pentachlorophenol	3.2	Alabama	1948	17
Cold-soaking	Pentachlorophenol	5.7	Mississippi	1956	....
Cold-soaking (48)	Pentachlorophenol	2.0[3]	Texas	1963	....

Table 18.—*Service life of hardwood fence posts by species, treating method, preservative, and exposure site. (Data from Anonymous 1960; Kulp 1966; Gjovik and Davidson 1975.)—Continued*

Species and treatment method (and time, hours)	Preservative		Exposure state	Year installed	Service life
	Material	Retention			
		pounds/cu ft			*years*[1]
Cold-soaking (123)	Copper naphthenate	7.1	Tennessee	1954	11
Cold-soaking (72)	Copper naphthenate	7.1	Tennessee	1954	....
Cold-soaking	Copper naphthenate	9.6	Mississippi	1956	...
Red maple					
Hot-and-cold bath	Creosote	....	Maryland	1908	32
Cold-soaking (23)	Pentachlorophenol	6.1	Tennessee	1951	15
Cold-soaking (53)	Pentachlorophenol	5.6	Tennessee	1949	22
Cold-soaking (46)	Copper naphthenate	4.3	Tennessee	1953	7
Scarlet oak					
Cold-soaking (44)	Pentachlorophenol	3.9	Tennessee	1949	....
Cold-soaking (48)	Copper naphthenate	4.7	Tennessee	1953	12
Cold-soaking (55)	Copper naphthenate	5.7	Tennessee	1953	14
Cold-soaking (47)	Copper naphthenate	5.2	Tennessee	1954	...
Southern red oak					
Cold-soaking	Pentachlorophenol	5.6	Mississippi	1953	....
Cold-soaking	Pentachlorophenol	3.9	Mississippi	1947	23
End diffusion	Zinc chloride	.95	Mississippi	1947	9
Double diffusion	[5]	1.0	Georgia	1955	21
Double diffusion	[5]	1.6	Georgia	1955	22
Double diffusion	[5]	2.1	Georgia	1955	16
Cold-soaking (48)	Pentachlorophenol	6.2	Mississippi	1948	....
Cold-soaking (48)	Pentachlorophenol	5.0	Mississippi	1956	....
Cold-soaking (48)	Pentachlorophenol	6.4	Mississippi	1951	....
Cold-soaking (84)	Copper naphthenate	7.6	Mississippi	1951	11
Cold-soaking	Copper naphthenate	9.2	Mississippi	1956	....
Sweetgum					
Pressure	Boliden salt	.78	Mississippi	1957	....
Pressure	Creosote	9.7	Mississippi	1957	....
Hot-and-cold bath	Creosote	7.7	Louisiana	1909	23
Hot-and-cold bath	Creosote	....	Maryland	1908	14
Pressure	Creosote	6.0	Mississippi	1937	23
Pressure	Creosote	12.0	Mississippi	1937	34
Hot-and-cold bath	Pentachlorophenol	2.3-10.0	Mississippi	1947	15
Cold-soaking (48)	Pentachlorophenol	4.9	Mississippi	1947	21
End diffusion	Zinc chloride	.95	Mississippi	1947	7
Double diffusion	[5]	1.9	Georgia	1955	19
Water oak					
Hot-and-cold bath	Creosote	8.4-9.6[2]	Mississippi	1941	27
Hot-and-cold bath	Pentachlorophenol	2.7-5.6[2]	Mississippi	1947	....
Water tupelo					
Hot-and-cold bath	Creosote	8.6	Louisiana	1908-10	23
Cold-soaking (120)	Pentachlorophenol	6.5	Mississippi	1953	22
End diffusion	Zinc chloride	.94	Mississippi	1947	5
White oak					
Pressure	Chromated copper arsenate	.28	Mississippi	1957	....
End diffusion	Chromated zinc chloride	.75	Wisconsin	1946	29
Hot-and-cold bath	Creosote	....	Maryland	1908	37
Pressure	Creosote	8.1	Mississippi	1957	..
Steeping	Zinc chloride	1.1-1.8	Wisconsin	1940	16
Double diffusion	[5]	1.3-2.3	Georgia	1955	16-21
Yellow-poplar					
Double-diffusion	[5]	2.0	Georgia	1955	19

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[1] Estimated average life of posts in tests. The most common method of determination of service life is use of mortality curves (such as those developed for crossties). An estimate of service life can be made when as few as 11 percent of the posts have failed. Other authors whose data are cited in this table made no estimate of service life until 60 percent of the posts had failed. Dot leaders (. . .) in this column indicate that an insufficient number of posts had failed at the last inspection to permit an estimate of service life.

[2] Mixed round and split posts.

[3] Split posts.

[4] Copper sulfate-sodium chromate.

[5] Zinc sulfate and arsenic acid-sodium chromate.

Table 19.—*Service life of untreated hardwood posts of 16 species (Gjovik and Davidson 1975)*

Species	Form	Location of test	Service life
			years
Ash, green	Round	Halsey, Nebraska	18.7
Ash, green	Round	Miles City, Minnesota	8.6
Ash, white	Round	Madison, Wisconsin	4.3
Elm, slippery	Round	Oregon, Wisconsin	3.8
Hickory, mockernut	Round	Saucier, Mississippi	3.5
Hickory, shagbark	Round	Oregon, Wisconsin	4.0
Hickory, sp.	Round	Norris, Tennessee	4.7
Hickory, sp.	Round	Saucier, Mississippi	2.8
Maple, red	Round	College Park, Maryland	3.8
Oak, black	Round	Norris, Tennessee	2.8
Oak, blackjack	Square	Madison, Wisconsin	8.4
Oak, blackjack	Round	Ava, Missouri	6.0
Oak, blackjack	Square	Madison, Wisconsin	7.9
Oak, southern red	Round	Saucier, Mississippi	2.8
Oak, red sp.	Round	Athens, Georgia	4.3
Oak, overcup	Round	Stoneville, Mississippi	4.3
Oak, overcup	Split	Stoneville, Mississippi	5.0
Osage orange	Round and split	Childress, Texas	43.0
Sweetbay	Round	Saucier, Mississippi	1.6
Sweetgum	Round	Athens, Georgia	2.2
Sweetgum	Round	College Park, Maryland	4.2
Sweetgum	Round	Wilson Dam, Alabama	2.3
Sweetgum	Round	Saucier, Mississippi	1.8
Tupelo, black	Round	Norris, Tennessee	3.4
Tupelo, black	Round	College Park, Maryland	4.2
Tupelo, water	Round	Saucier, Mississippi	2.1

Schrader (1945) determined the effect of incising on the strength of Douglas-fir laminated beams. Beams 8 × 18 inches in cross section fabricated from 1-inch lumber and beams 8 × 16 inches prepared from 2-inch lumber sustained reductions in bending strength of from 10 to 20 percent as a result of ⅝-inch-deep incisions applied at a rate of 65 per square foot. Banks (1973) found that 2- by 2-inch samples of Norway spruce (*Picea abies L.* Karst.) lost 16 and 13 percent of their MOR and MOE, respectively, following incising to a depth of ¼-inch with 860 incisions per square foot. Similar depths and frequencies of incisions on redwood (*Sequoia sempervirens* (S. Don) Endl.) dimension sized for use in cooling towers reduced bending strength by 7 to 28 percent (Kass 1975).

From the limited data available on the effect of incising on the strength of hardwoods, it can be surmised that effects are similar to those for softwoods. A study of strength losses sustained by small hardwood posts prepared for non-pressure preservative treatment (Chudnoff and Goytia 1967) tends to confirm this. Incising at a rate of 160 incisions per square foot caused a reduction of MOR of about 14 percent.

Conditioning

Steaming.—Steaming of wood reduces water content in green stock and renders it more permeable to preservatives. It is routinely applied to southern pine and certain other conifers but less frequently applied to hardwoods. Current industry standards (American Wood Preservers' Association 1977) do not permit steam conditioning of oak because of its susceptibility to damage from this process. While steaming is permitted with other hardwoods, those that receive preservative treatment are mainly for crossties, conditioned usually by air drying, Boultonizing, or vapor drying.

Steam conditioning at the pressures and durations permitted under existing standards may cause significant strength losses in treated products. Buckman and Reese (1938), Davis and Thompson (1964), MacLean (1951), and Wood et al. (1960) show conclusively that above certain temperatures wood undergoes chemical degradation and sustains losses in strength to a degree dependent upon the duration and severity of exposure.

Wood heated in an atmosphere of steam loses weight, becomes discolored, sustains reductions in strength, and undergoes chemical degradation (Baechler 1954). At atmospheric pressure, effects are those of a mild hydrolysis, catalyzed by natural acids in the wood, becoming progressively more severe with increasing temperature and time of exposure. The carbohydrate fraction of wood, especially the hemicellulose component, is particularly susceptible to hydrolysis (MacLean 1951).

Much of the original work on the effect of steaming on the mechanical properties of wood was conducted

Table 20.—*Treating and service-life data for sweetgum fence posts. (Data from Kulp 1966; Anonymous 1960).*

Treating method (and time, hours)	Preservative		Age at last inspection	Exposure state	Number in test	Failure	Service life[1]
	Material	Retention					
		pounds/cu ft	*years*			*percent*	*years*
Cold-soaking (26)	Pentachlorophenol	6.8	11	Mississippi	23	44	13
Cold-soaking (. . .)	Pentachlorophenol	6.3	8	Mississippi	292	41	9
Cold-soaking (48)	Pentachlorophenol	5.1	14	Georgia	23	39	16
Cold-soaking (24)	Pentachlorophenol	4.7	14	Georgia	18	33	17
Cold-soaking (72)	Pentachlorophenol	5.8	14	Georgia	25	28	18
Cold-soaking (72)	Pentachlorophenol	5.7	14	Georgia	24	4	
Cold-soaking (72)	Pentachlorophenol	6.4	13	Georgia	26	8	
Cold-soaking (144)	Pentachlorophenol	7.2	14	Georgia	25	1	
Cold-soaking (24)	Pentachlorophenol	5.5	15	Alabama	28	14	22
Cold-soaking (6)	Pentachlorophenol	5.0	15	Alabama	27	85	11
Cold-soaking (72)	Pentachlorophenol	5.6	12	Texas	65	0	
Cold-soaking (72)	Pentachlorophenol	5.6	13	Texas	98	0	
Cold-soaking (72)	Pentachlorophenol	5.6	13	Texas	97	0	
Cold-soaking (72)	Pentachlorophenol	5.6	12	Texas	30	0	
Cold-soaking (12)	Pentachlorophenol	5.1	12	Virginia	5	80	10
Cold-soaking (48)	Pentachlorophenol	4.1	12	Virginia	11	48	13
Cold-soaking (105)	Copper naphthenate	7.0	8	Mississippi	50	18	11
Cold-soaking (24)	Copper naphthenate	4.4	14	Georgia	47	56	15
Cold-soaking (48)	Copper naphthenate	5.4	14	Georgia	24	38	16
Cold-soaking (72)	Copper naphthenate	4.2	14	Georgia	22	64	14
Cold-soaking (144)	Copper naphthenate	5.7	15	Georgia	23	52	14
Cold-soaking (0.3)	Copper naphthenate		6	Tennessee	17	35	7
End diffusion	Zinc chloride	.9	6	Mississippi	200	34	7
End diffusion	Zinc chloride	.4	12	Georgia	50	82	6.5
End diffusion	Zinc chloride	.6	10	Georgia	24	96	6
	None		. .	Georgia	24	100	3.0
	None		. .	South Carolina	21	100	1.0
	None			Mississippi	24	100	2.2
	None		. .	Louisiana	25	100	2.0

[1] Estimated average life of posts in test. Dot leaders ( ) in this column indicate that an insufficient number of posts had failed at the last inspection to permit an estimate of service life.

Table 21.—*The effect of incising on the strength of Douglas-fir timbers and ties (Adapted from Perrin 1978)*

Dimensions	Incisions per square foot	Change in strength						
		Bending[1]			SH[2]	Compression[3]		
		PL	MOR	MOE		CS	MOE	FS
inches	*number*	*percent*						
4×8	64	− 8	−15	− 4	. .	− 4	. .	− 7
4×8	64	−18	−15	−14	. .	−17	. . .	−33
4×8	64	− 4	− 9	− 4		− 3	.	+ 3
4×8	64	+ 2	+11	− 6	. . .	− 5		− 5
6×12	56	− 2	− 2	. .	−2	.		
6×12	56	+ 1	− 2	. .	−2	.	. .	
6×12	75	− 2	0	− 7	0	.		
6×12	75	− 4	− 7	− 4	−7			.
7×8	75							−10
7×9	76				.	.	.	− 8
7×9	76	+ 6	+ 4	0	0	+ 3	0	+ 6
7×10	90							+17

[1] PL-proportional limit stress, MOR-modulus of rupture, MOE-modulus of elasticity.

[2] SH—shear parallel to grain.

[3] CS—crushing strength parallel to grain; MOE in compression parallel to grain; FS—compression strength perpendicular to grain.

by MacLean (1951, 1952, 1953). Following a study in which small specimens were steamed at temperatures of 250°F to 350°F for 8 to 32 hours, he concluded that shock resistance was the property most seriously affected, followed in order by MOR, fiber stress at the proportional limit, and MOE (MacLean 1953). An identical order of effect was reported by Thompson (1969a) based on bending tests of Class 6, 30-foot southern pine poles. In the latter study, MOR was reduced about 37 percent, from 7,902 psi to 5,707 psi, as a result of steaming 14 hours at 245°F.

The limited data available on hardwoods indicate they are more susceptible to damage from steaming than are softwoods. Davis and Thompson (1964) found that the residual toughness of small red oak specimens following steaming at 138°C for 120 minutes was only 60 percent of the control values, a greater reduction than those for southern pine and Douglas-fir specimens similarly treated. Chemical analyses of these specimens revealed that the reduction in strength was well correlated with changes in chemical composition. The carbohydrate fraction was more seriously degraded in oak than in either of the two coniferous species.

Kubinsky (1971) reported that compressive strength of small red oak cubes was reduced by 20 and 23 percent in the tangential and radial directions after steaming for 6 hours at atmospheric pressure. Reductions after exposure for 96 hours were 55 and 49 percent, respectively. Thompson (1969b) found a 14 percent reduction in compressive strength for southern pine piling sections steamed 16 hours at 245°F. While specimen size differed, results suggest that hardwoods are more sensitive to steaming than softwoods.

Further substantiation of this statement is provided by extensive research conducted by MacLean (1951, 1953). Weight losses resulting from heating small specimens for 17.4 days in water at 250°F were as follows for the species indicated:

Species	Weight loss
	Percent
Yellow birch	38
Yellow-poplar	37
Basswood	36
White oak	36
Sweetgum	34
Hard maple	33
Southern pine	28
Douglas-fir	25
White pine	24
Sitka spruce	24

Although this order of effect of thermal treatments was not maintained for all combinations of temperatures and heating mediums employed by MacLean (1951), the hardwoods were far more sensitive than the softwoods in all tests.

Boulton Drying. —Conditioning by the Boulton process has less deleterious effects on wood than steaming because of the lower temperatures (180-210°F) used. As in the case of steaming, strength reductions caused by the process at a given temperature are determined by the duration of the conditioning process, by species, and by the size of items involved.

Data of the effects of Boulton-drying are lacking for hardwood species. Based on the experience with other forms of thermal treatment, it is probable that they would be at least equal to those for softwoods. Data compiled by Graham (1980) on the effect of three conditioning processes on the strength of Douglas-fir sawn products are of interest (table 22). Reductions in MOR for timbers in the size range from 6 × 12 to 8 × 16 inches that were Boultonized at temperatures of 190° to 215°F ranged between 5 and 18 percent and averaged about 10 percent in tests conducted by Rawson (1927), MacFarland (1916), Luxford and MacLean (1951), and Harkom and Rochester (1930). Reductions in MOR for 1-inch and 2-inch stock exposed to the same temperature averaged almost 12 percent; items in this size class that were kiln-dried or vapor-dried in the temperature range of 220° to 250°F sustained reductions in MOR of 18 to 21 percent. Rawson's study of the effect of Boulton drying on Douglas-fir timbers was superimposed on a study of the effect of incising. The modest reduction in MOR of 6 percent attributed by the authors to the Boulton process was higher than the apparent reduction caused by incising —about 2 percent.

Reductions in MOR caused by Boultonizing for 30-foot Douglas-fir and western larch poles were reported by Wood et al. (1960) to be of the same order of magnitude as those for sawn products (table 23). Larch was the more seriously affected, showing a decrease in MOR and MOE of 17 and 20 percent, respectively. However, these values were smaller than the reductions sustained by steam conditioned southern pine, which ranged from 23 to 34 percent for MOR and 12 to 16 percent for MOE.

Vapor Drying.—The effect of this conditioning process on wood strength is somewhat greater than that of Boulton-drying because of the higher temperatures employed. Eddy and Graham (1955) found reductions in MOR of 9, 18, and 21 percent following vapor drying of 2- by 2-inch Douglas-fir at 190, 225, and 250°F, respectively. Reductions in work to maximum load were, in order, 17, 36, and 49 percent.

Strength reductions in oak and gum crossties attributed to vapor drying are of the same order of magnitude (table 24) notwithstanding the large difference in cross-sectional dimension of the test specimens: 2 by 2 inches compared to 7 by 9 inches. The MOR of untreated vapor-dried ties at 8,025 psi was about 8.3 percent less than that for matched air-dried ties. The comparable reduction for fiber stress at the proportional

Table 22.—*Effect of conditioning temperature on the modulus of rupture of Douglas-fir (Graham 1980)*

Reference	Specimen size	Reduction of MOR as fraction of control values[1] 140 to 170°F	190 to 215°F	220 to 230°F	250°F	Heat source
	inches	*percent*				
Eddy and Graham (1955)	2×2		9	18	21	Organic vapors
	2×2	4				Kiln drying
Graham (1980)	1×1			16		Organic vapors
	1×1	7	16			Kiln drying
Harkom and Rochester (1930)	6×12		13			Boulton drying
Kozlik (1968)	2×6	1	10	21		Kiln drying
Luxford and MacLean (1951)	4×8		4			Boulton drying
	8×16		9			Boulton drying
	8×16		12			Boulton drying
	8×16		7			Boulton drying
	8×16		8			Boulton drying
MacFarland (1916)	7×16		18			Boulton drying
Rawson (1927)	6×12		5			Boulton drying
	6×12		7			Boulton drying

[1] Adjusted for differences in moisture content between treated and control specimens.

limit in compression perpendicular to the grain was 11.9 percent. For reasons that are unclear, the reduction in both strength properties was increased if the ties were water soaked prior to testing. Thus, the MOR of air-dried, water-soaked oak ties was 8,320 psi compared to 6,760 psi for vapor-dried, water-soaked ties, an apparent reduction due to vapor drying of almost 19 percent. The same effect is evident in the data for gum crossties.

Effect Of Treating Cycle

Woods with low permeability sometimes sustain cell collapse under high temperatures and pressures in wood preserving. The incidence of collapse varies both within and among species, as well as with the treating conditions imposed. Thus, Rosen (1975b) found that both white oak and red oak collapsed at a pressure of 1,000 psi when the temperature was 75°F and at 500 psi when the temperature was 200°F. James (1961), however, found no collapse in red oak following pressure treatments conducted at 1,000 psi and 200°F. Likewise, Walters and Guiher (1970) successfully treated redgum (sweetgum) at 800 psi and 200°F without inducing collapse. Walters (1967) found collapse of sweetgum only in specimens subjected to pressure greater than 400 psi. It varied from slight to severe depending upon treating temperature and wood moisture content.

In red oak specimens, following treatments covering pressure and temperature ranges of 200 to 800 psi and 100 to 200°F, respectively, James (1961) detected no collapse in any of the specimens. Toughness reductions increased with the severity of treating conditions and ranged from about 6 percent (200 psi, 100°F) to about 11 percent (800 psi, 200°F).

While temperature and pressure are important, the refractory nature of collapse-prone species is a basic cause of collapse during preservative treatment. Unlike easily penetrated species, in which pressures are rapidly equalized by the flow of preservative into cell lumens, refractory species permit large pressure differentials to develop, inducing collapse of cells.

Stabilization Treatments

Rowell and Youngs (1981) noted that "there are two basic types of wood treatments for dimensional stability: (1) those which reduce the rate of water vapor or liquid absorption but do not reduce the extent of swelling to any great degree, and (2) those which reduce the extent of swelling and may or may not reduce the rate of water absorption (fig. 13). Terms most often used to describe the effectiveness of the first type of treatment are moisture-excluding effectiveness (MEE), which can be determined in either water or water vapor form, and water repellency (WR), which is a specific liquid test. The term used to describe the effectiveness of the second type of treatment is reduction in swelling (R) or antishrink efficiency (ASE). Most of the type (1) treatments have very low R or ASE values. The R or ASE values can be determined in water vapor tests or single-soak liquid test for water-leachable treatments, or in double-soak liquid tests for nonleachable treatments.

"In selecting a treatment to achieve product stability to moisture, at least three factors must be considered. The environment of the end product is the most important factor. If the product will come into contact with water, nonleachable—and perhaps even bonded—treatments will be needed. If, however, the product will be

Table 23.—*Effect of conditioning method on the strength of 30-foot poles (Wood et al. 1960)*

Species	Conditioning method	Modulus of rupture	Modulus of elasticity
		(Fraction of unseasoned controls)	
		percent	
Longleaf and slash pines (*Pinus palustris* Mill. and *P. elliottii* Engelm.)	Steam and vacuum[1]	−23	−12
Shortleaf and loblolly pines (*Pinus echinata* Mill. and *P. taeda* L.)	Steam and vacuum[1]	−34	−16
Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco)	Boulton drying[2]	− 7	− 4
Western larch (*Larix occidentalis* Nutt.)	Boulton drying[2]	−17	−20
Lodgepole pine (*Pinus contorta* Dougl.)	Air drying	+ 4	+ 3
Western redcedar (*Thuja plicata* Donn)	Air drying	− 4	− 1

[1] Steaming conditioning was conducted at 259°F for 8.5 to 13.5 hours.

[2] Boulton drying was conducted at 195 to 210°F for 16 to 30 hours with a vacuum of 17 to 25 inches of mercury.

subjected to changes in relative humidity in an indoor environment, a leachable or water-repellent treatment might be satisfactory. The degree of dimensional stability must also be considered. If very rigid tolerances are required in a product—as in pattern wood dies—a treatment with very high R or ASE values is needed. If, on the other hand, only a moderate degree of dimensional stability is satisfactory, a less rigorous treatment will suffice. A final consideration is the cost effectiveness of a treatment. For example, the millwork industry uses a simple wax dip treatment to achieve a moderate degree of water-repellency. They would, no doubt, like a higher degree of water repellency or dimensional stability, but the cost to achieve this may not be recoverable in the marketplace. On the other hand, musical instrument makers require a very high degree of dimensional stability and the value of the final instrument can absorb the high cost to accomplish the desired results."

Readers interested in a general review of stabilization treatments such as cross lamination, water resistant coatings, hygroscopicity reduction, crosslinking, and bulking should read Rowell and Youngs (1981). Some research results specific to eastern hardwoods follow.

Typically, small specimens have been treated with polyethylene glycol or monomers, such as styrene and methyl methacrylate, which are subsequently polymerized *in situ* by heat (Siau and Meyer 1966) or gamma radiation (Siau et al. 1965). Treatment efficiency, as assessed by reduction in dimensional changes or volumetric swelling associated with changing moisture conditions, is a function of the fractional void volume of the wood filled by the chemical—a function of wood permeability and moisture content at time of treatment. Impregnation by pressure and vacuum processes has been used for treatments with monomers, while polyethylene glycol is applied by soaking unseasoned wood in a 30 to 50 percent aqueous solution of the chemical for several days or weeks, depending upon specimen size. Cost has limited the use of stabilization treatments to high-value items requiring above normal dimensional stability (Hallock and Bulgrin 1972).

Siau and Meyer (1966) reported that mechanical properties of yellow birch specimens impregnated (average loading 97 percent) with methyl methacrylate differed by curing method. Curing was by heat (68°C for 19.5 hours) or gamma radiation (0.64 megarads/hour for 4.7 to 15.6 hours). Mean compression strength was 11,700 psi for the 3 to 10 megarads treatment and 12,180 psi for heat. Values for control specimens averaged 2,905 psi. Thus, impregnations with methyl methacrylate improved compressive strength by an average factor of 4.11. Shear strength was not affected by treatment. Surface hardness was 25 percent greater in irradiated than in heat-cured specimens, ascribed by the authors to a preferential loss of monomer near the surface during heat curing. Antishrinkage efficiency was only 7.3 percent, thus suggesting that only small quantities of the monomer penetrated cell walls.

Much higher antishrinkage efficiencies—up to 80 percent—were reported by Siau et al. (1965) following irradiation curing of styrene-impregnated yellow-poplar. Retentions of 80 to 200 percent (based on ovendry wood weight) were obtained using solvent exchange and vacuum methods. Best results were achieved with dioxane, methanol, or ethanol as solvents. In later work, Siau (1969) found that volumetric swelling of up to 9 percent may occur in basswood following prolonged immersion in methyl methacrylate and styrene and after wood-polymer composites have been made using these materials. The amount of swelling was reported to be a function of temperature and moisture content of the wood. Siau et al. (1975) found that both smoke evolution and flamespread are significantly increased by the presence in wood of polymers whose structure includes benzene rings.

Table 24.—*Strength of green, air-seasoned, and vapor-dried 7- by 9-inch oak and gum crossties*[1]

Species group and condition at time of test	Modulus of rupture	Fiber stress at proportional limit in compression perpendicular to the grain
	psi	
Oak (*Quercus* sp.)[2]		
Green	9,560	804
Air-dried, water-soaked	8,320	706
Air-dried	8,754	687
Air-dried, creosoted, water-soaked	8,360	800
Air-dried, creosoted	8,920	811
Vapor-dried, water-soaked	6,760	474
Vapor-dried	8,025	605
Vapor-dried, creosoted, water-soaked	6,360	459
Vapor-dried, creosoted	8,250	611
Gum (sweetgum and black tupelo)[3]		
Green	8,604	685
Vapor-dried, water-soaked	7,500	446
Vapor-dried	7,828	490
Vapor-dried, creosoted, water-soaked	6,010	490
Vapor-dried, creosoted	7,390	792

[1] Data provided by M. S. Hudson, Spartanburg, S.C.

[2] Each value is the average of 32 tests.

[3] Each value is the average of 12 tests.

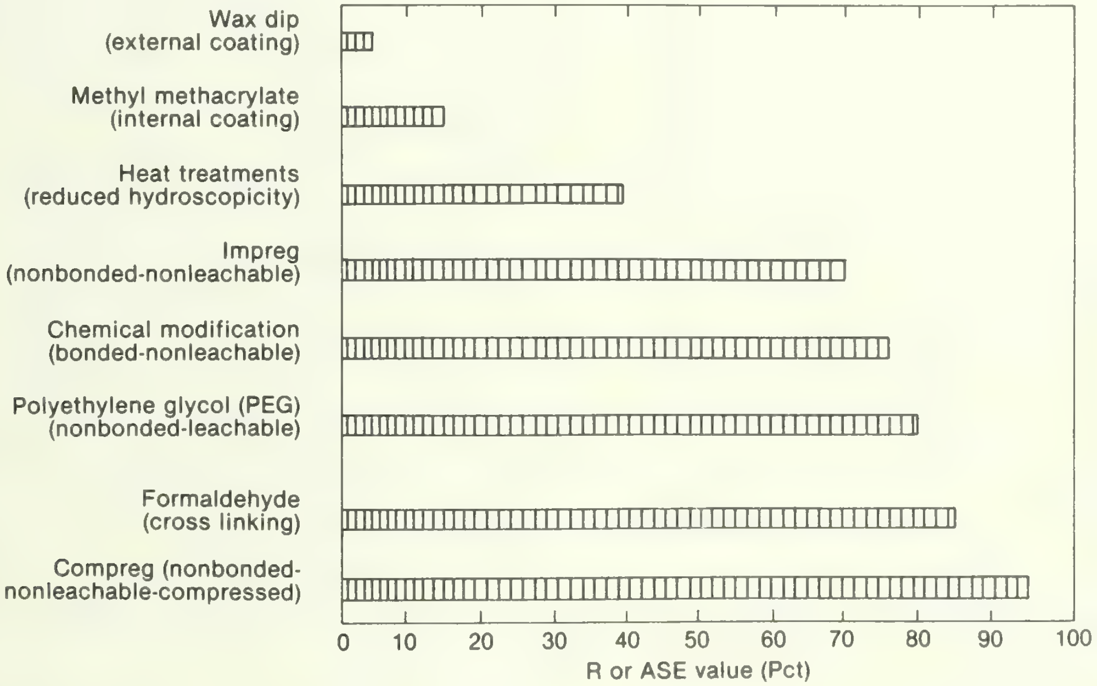

Figure 13.—*Comparison of wood treatments and the degree of dimensional stability achieved. Impreg is laminated from veneers impregnated with phenol-formaldehyde resin. Compreg is made by densifying layers of resin-impregnated veneer by application of heat and pressure up to 1,000 psi. (Drawing after Rowell and Youngs 1981).*

Unlike Siau and Meyer (1966), Loos and Kent (1968) found significant increases in shear strength of yellow-poplar following loadings of 50 to 100 percent with methyl methacrylate.

The addition of waxes to styrene and methyl methacrylate monomers prior to impregnation of wood was reported by Lan and Rosen (1978) to affect adversely the polymerized properties of the wood-polymer composite. Application of waxes to the surface of composites provided water and water-vapor resistance superior to all wax-monomer combinations.

Antishrink efficiencies of 60 to 70 percent have been reported for softwood samples treated with methyl isocyanate to weight gains of 16 to 28 percent (Rowell and Ellis 1979). Volumetric changes resulting from treatment were approximately equal to the volume of chemical absorbed, thus indicating that a chemical addition took place within the cell wall. Decay resistance was imparted by the treatment. At weight gains greater than about 26 percent, part of the chemical could be leached from the wood, and electron micrographs revealed cell-wall splitting.

Hallock and Bulgrin (1972) and Merz and Cooper (1968) have shown the efficiency of polyethylene glycol (molecular weight 1000) in reducing shrinkage and warpage of wood during drying and in service. The latter authors, who worked with black oak specimens 3 × 1½ × 1½ inches long, reported that treatment durations of 96 hours at 130°F to 150°F provide antishrink efficiencies of 50 to 65 percent and that further gains from longer treatments are of little practical significance. Hallock and Bulgrin subjected maple flooring to a treatment regime in polyethylene glycol that included solution temperatures as high as 200°F. Exposure at this temperature for 10 days produced a 22 percent retention and essentially no shrinkage upon drying.

Irradiation of wood has been employed commercially in the production of wood-polymer composites. The effect of irradiation on the mechanical properties of the wood varies with dosage and also apparently with species. Loos (1962) reported an increase in toughness of specimens of yellow-poplar for gamma radiation dosages up to about 0.85×10^5 rads. Toughness was reduced by as much as 28 percent, however, by levels in the range of 1.0×10^7 rads.

A significant increase in MOR was reported by Shuler et al. (1975) for specimens of American elm cut from saplings that had been exposed for 5 years to a gamma radiation level of 22,000 roentgens. By contrast, maximum work was decreased by all radiation levels studied by these authors.

Recommendations for Future Research.—Rowell and Youngs (1981) identified some specific research avenues that need further investigation. They noted that the "properties of coatings can be tailored to perform more duties than just water repellency. A water-repellent coating could also serve as an ultraviolet screen or flameproofing shield. It could also contain bound functional insecticides or fungicides that could protect the wood from attack by insects and decay organisms."

"In bonded bulking treatments, the bound chemical could be a fire retardant if the bonded chemical has an adequate distribution in the wood structure; thus, the treated wood would be both dimensionally stabilized and resistant to attack by termites, decay organisms, and marine organisms. Chemical modification of wood could provide a variety of nonleachable treated wood products that are both dimensionally stabilized and fire retardant or nonbiodegradable or acid and base resistant."

Complete dimensional stability of wood (R or ASE = 100) has never been achieved, and perhaps never will be; there is much yet to be learned about wood-moisture relationships (Rowell and Youngs 1981).

Effect Of Preservatives

Solid-Wood Products.—The pH of treating solutions of some water-borne preservative formulations must be maintained within certain limits to prevent precipitation of the heavy-metal salts of which they are composed. Some of the solutions may be quite acid. Thus, for example, chromated copper arsenate (CCA) solutions may have a pH as low as 1.9, and the acidity of acid copper chromate (ACC) solutions may range from pH 2.0 to 3.9. By contrast, ammoniacal copper arsenate (ACA) is quite alkaline since solutions of this preservative must contain a weight of ammonia equal to 1.5 to 2.0 times the weight of the copper oxide; copper oxide comprises 47.7 percent of the dry weight of the formulation.

The effect of the pH of the treating solution and, indeed, the effect of the preservative salts themselves on wood properties have not been clearly defined. Thompson (1964b) investigated the effect of CCA, ACA, and ACC on the toughness of sweetgum, yellow-poplar, and black tupelo veneer for retention levels of 1 to 4 pounds per cubic foot. Toughness of sweetgum and yellow-poplar was not significantly affected by the treatments. Black tupelo, however, sustained important reductions in toughness, the values varying with retention. At retentions greater than about 1.0 pound per cubic foot, embrittlement was observed in specimens of all species; yellow-poplar was least affected. Subsequent analyses of the specimens revealed that the chemical composition of the wood, particularly carbohydrate content, was altered by high retention of all three preservatives.

Additional evidence that high retentions of salt-type preservatives may reduce the shock-resistant properties of timbers was supplied by Wood et al. (1980). Specimens cut from southern pine pole sections treated

Table 25.—*Effect of high retentions of a CCA-type preservative on the mechanical properties of southern pine (Wood et al. 1980)*

Strength value	Retention (pounds/cu ft)[1]			
	0	1.0	1.2	2.5
Modulus of rupture (psi)	16,350	16,450	16,350	15,500
Modulus of elasticity (million psi)	2.21	2.18	2.06	2.08
Fiber stress at proportional limit (psi)	8,775	8,215	8,580	8,450
Work to proportional limit (in-lb/cu in)	1.98	1.75	2.04	1.96
Work to maximum load (in-lb/cu in)	14.4	15.2	14.6	10.7
Toughness (in-lb)	236	223	219	165
Compressive strength parallel-to-grain (psi)	3,355	3,485	3,530	4,500

[1] Each value is the average of 32 measurements.

with CCA to a retention of 2.5 pcf had significantly lower values of toughness and work to maximum load than untreated control specimens. Although not significant statistically, there was a trend toward lower bending strength among specimens treated to this retention. Wood's data (table 25) showed no effect on strength properties at retention values lower than 2.5 pcf. This is consistent with Kelso's[4] data showing no deleterious effects of CCA retentions less than 1 pcf on strength of wood.

How reduced shock resistance revealed by impact studies of small specimens translates to full-size structural members is unknown. Marine piling is the only item for which retentions of CCA-type preservatives in excess of 2.0 pcf are employed. Definitive data on the effect of such treatments on piling are not available, but it is generally conceded within the industry that piling treated with CCA tend to break during driving more frequently than those treated with creosote. Likewise, data are much too limited to permit more than speculation on how the strength properties of load-bearing hardwood members, such as railroad ties, are affected by preservative salts. Even if it is assumed that these chemicals would have a more serious effect on hardwoods than softwoods, it is unlikely that the effect would have practical significance because of the relatively low retentions used.

Strength reductions associated with treatments with oil-type or oil-borne preservatives are attributed to conditioning and not to the preservatives themselves. For example, it has been shown that the crushing strength of 3-foot piling sections cut from kiln-dried southern pine stock and treated with creosote was essentially the same as that for untreated, matched controls (Thompson 1969b). Reductions in this strength property occurred only among specimens that were steam conditioned preparatory to treatment. Similarly, the data shown in table 24 for oak and gum crossties show essentially no effect of the creosote per se on strength properties.

Published data also indicate that preservatives interfere with bonding of treated wood (Selbo 1959a; Blew and Olson 1950). Reductions in both shear strength and wood failure (i.e., increased glueline failure) have been reported for treated compared to untreated laminated wood. These reductions are attributed to changes in the surface properties of wood brought about by the preservative chemicals.

The effect of preservative salts on gluing properties and bond quality of sweetgum was evaluated by Thompson (1962). One-eighth-inch veneer pieces treated to a gradient series of retentions with each of four waterborne perservatives were bonded to form three-ply samples using three different adhesives (table 26). Retentions of 3.0 pcf greatly reduced both shear strength and wood failure for all combinations of adhesives and preservatives. Retentions of sodium pentachlorophenate between 0.37 and 1.50 pcf had little deleterious effect on bond quality for any of the adhesives. The effect of lower retentions of the three inorganic salt formulations varied among adhesives, with phenol formaldehyde resin showing the poorest results. Among preservatives, acid copper chromate most seriously reduced bond quality. With the exception of specimens treated with sodium pentachlorophenate, most of the average wood failure values (table 26) were much too low to meet applicable standards.

Similar results were obtained by Bergin (1962) who studied the gluability of birch veneer treated with fire-retardant chemicals to retentions of 6.2 to 9.5 pcf of anhydrous chemical. None of the 11 adhesives employed in the study produced exterior-quality bonds when the veneer was treated with a fire retardant composed of zinc chloride, ammonium sulfate, and boric acid. Serious interference with gluing was also recorded for fire retardants composed of ammonium phosphate and ammonium sulfate, but a special resorcinol adhesive met specifications for exterior-quality bonds in plywood treated with that formulation.

Table 26.—*Effect of preservative retention of 0.37 pcf on wood failure in sweetgum veneer specimens bonded with three adhesives and tested both wet and dry. (Adapted from Thompson 1962.)*

Preservative	Adhesives					
	Resorcinol-phenol		Phenol		Melamine	
	Wet	Dry	Wet	Dry	Wet	Dry
	percent wood failure					
Sodium pentachlorophenate (PCP)	90	89	58	92	100	100
Acid copper chromate (ACC)	15	3	72	28	4	5
Ammoniacal copper arsenate (ACA)	85	22	48	56	31	12
Chromated copper arsenate (CCA)	48	40	3	35	42	48
Controls	94	90	88	89	100	100

Block-shear values of red oak treated with a range of preservatives before bonding were reported by Selbo (1959b) to be lower after each exposure period (3 to 36 months) than matched controls. Reductions in shear values attributed to the preservatives ranged from about 4 to 16 percent.

Reconstituted and Composite Wood Products.—The increased use of reconstituted board products, with or without veneer overlays,as paneling products in home, hospital, and school construction and in applications where insect or decay hazards exist has prompted several studies of fire-retardant and preservative treatments of these products (Anonymous 1978; Surdyk 1975). Treatments are usually applied to the wood particles prior to application of adhesive and forming, because concurrent application of the preservative or fire-retardant with the resin adversely affects adhesive properties (Johnson 1964). Huber (1958), however, successfully treated both hardboard and particleboard by adding sodium pentachlorophenate to the adhesive in amounts equivalent to 0.65 percent of dry wood weight, without adversely affecting MOR or dimensional properties of the boards produced.

Brenden (1974) reported reduced peak heat release from building materials commercially treated with fire retardant salts: three-fourths-inch Douglas-fir plywood from 611 to 132 Btu/min/ft^2, and a gypsum wallboard-Douglas-fir stud assembly from 206 to 105 Btu/min/ft^2.

Flame-spread ratings ranging from good to excellent have been achieved with particleboard by spraying a volume of solution equivalent to 3 to 5 pcf on the furnish and redrying subsequent to boardmaking (Gilbert 1962). Arsenault (1964), however, found that two commercial fire-retardants added to aspen furnish prior to pressing into flakeboard seriously interfered with bonding. Sharp reductions in internal bond and bending strength were induced by all retentions between 2 to 8 pcf. Reductions in these strength properties occurred only in the case of urea-bonded boards treated with zinc borate; a formulation composed of dicyandiamide and ortho-phosphoric acid appeared to increase MOR.

Efforts to impart fire resistivity to hardboard by a bromination process have been unsuccessful because of the adverse effect of the treatment on board strength and water adsorption properties (Jurazs and Paszner 1978). Use of bromination to impart decay resistance to hardboard has been reported by Hong et al. (1978).

Reduction in hardboard flame spread of up to 60 percent were achieved by Myers and Holmes (1975) by treating the fiber furnish with a series of fire retardants in amounts equal to 10 percent of dry fiber weight (table 27). Ten of the formulations tested reduced MOR by 20 percent or less, while three reduced this property by 40 to 50 percent.

In later work Myers and Holmes (1977) tested 4- b 8-foot panels of a hardboard following treatment of th fiber furnish with disodium octaborate tetrahydrat boric acid (DOT-BA) or dicyandiamide-phosphor acid-formaldehyde (DPF). An application rate of 2 percent based on dry fiber weight was used. Bot treatments gave average flame-spread values that me criteria for Class B material—75 or under. Smoke deve opment with the DOT-BA treatment was quite low- 17 in the 25-foot tunnel test, compared to 399 fo untreated controls. This treatment reduced interna bond strength (IB) by 30 percent but had no effec on or increased other strength properties.

While it is the usual procedure either to add fire retardant chemicals to particleboard or fiberboard furnish prior to consolidation or to employ post-treatment in a pressure retort, Shen and Fung (1972) used a hot-pressing technique to accomplish this goal. Fire retardant chemicals (ammonium dihydrogen orthophosphate or liquid ammonium polyphosphate) were added to the surface of panels and forced into the surface by pressing the treated panels for a short period of time using temperatures and pressures of about 500°F and 250 psi, respectively. Surface loadings of up to 50 g/ft^2 were achieved in this manner. Flame spread was reduced from over 100 for untreated panels to less than 30 at loadings of 40 to 50 g/ft^2.

Strength and dimensional properties of phenolic-bonded particleboard prepared from ACA-treated flakes of 22 Ghanaian hardwood species were evaluated by Hall and Gertjejansen (1978). The effect of preservative retentions of 0, 0.2, 0.4, and 0.6 pcf on MOR, MOE, and IB (internal bond) for two resin levels and both the vacuum-pressure-soak-dry and accelerated-aging tests are summarized in figure 14. Percent thickness swelling is shown in figure 15 as a function of preservative retention, resin content, and type of test. This figure shows mechanical properties expressed as percentages of respective test values for control specimens—specimens which were not subjected to the vacuum-pressure-soak-dry or accelerated aging test, but which were in other respects treated like the remaining specimens.

All panels manufactured from flakes treated with preservative had lower MOR's and IB's than corresponding controls. MOR was reduced by preservative treatment by an amount equivalent to 5 percent for each 0.2-pcf increase in preservative retention. The effect of preservative treatment on IB was magnified by the weathering tests to an extent greater than that for the other strength properties. MOE was the strength property least affected by the preservative.

Thickness swelling was influenced more by resin content (either 5 or 8 percent) and method of test than by preservative retention. Treated boards had substantially higher thickness swelling than untreated

Table 27.—*Strength properties and fire performance of fire-retardant treated hardboards (Myers and Holmes 1975)*

Board treatment[3]	Bending properties[1]		Internal bond[1]	Fire performance			
				8-foot tunnel furnace			2-foot tunnel furnace[2]
	MOE	MOR		Flame-spread index	Fuel-contributed index	Smoke density index	Flame-spread index
	thousand psi	*psi*	*psi*				
Untreated (control)	694	6,120	439	119	128	302	111
	702	6,110	336	122	124	289	112
	752	6,490	299	119	151	375	122
Average	716	6,240	358	120	134	322	115
Untreated (¼-inch thick) (control)[2]	676	6,000	289	96	140	474	113
10-percent fire retardant treatment							
Water-soluble salts							
Disodium octaborate tetrahydrate	748	5,640	398	103	63	143	42
Disodium octaborate tetrahydrate-boric acid 94:1	772	5,910	369	97	66	82	42
Monoammonium phosphate[4]	680	4,600	307	92	50	708	75
Monoammonium phosphate (¼-inch thick)				83	46	594	86
Ammonium sulfate	725	4,760	349	90	86	254	62
Monoammonium phosphate-ammonium sulfate (1:1)	677	4,260	293	90	52	428	69
Diammonium phosphate	691	4,970	277	62	37	732	69
Diammonium phosphate-ammonium sulfate (1:1)	682	4,590	273	95	56	276	70
Borax	840	5,950	432	79	53	159	44
Borax-monoammonium phosphate (2:1)	634	5,000	385	83	72	141	62
Borax-boric acid (1:1)	739	6,040	257	83	55	221	50
AWPA Type C	659	4,190	248	109	88	89	71
AWPA Type D	624	3,040	233	93	76	176	74
Liquid ammonium polyphosphates[5]							
11-37-0	620	4,360	242	59	43	958	64
11-37-0 and ammonium sulfate (1:1)	684	4,220	264	93	60	568	61
12-44-0	586	3,730	178	48	23	954	61
Curing-type-organic phosphates							
THPC[6]	652	4,830	295	121	140	395	108
THPOH[7]	758	4,250	316	127	134	397	109
Dicyandiamide-phosphoric acid	822	5,430	281	79	45	641	64
Dicyandiamide-phosphoric acid-formaldehyde (pre-reacted)	797	5,630	265	83	53	485	67
MDP[8]	791	6,050	356	109	108	164	85
MDP[9]	627	3,700	232	79	69	694	81
Guanylurea phosphate	727	5,240	276	93	59	571	73
20-percent fire-retardant treatment							
Disodium octaborate tetrahydrate-boric acid (4:1)	796	6,610	349	69	22	281	44
12-44-0 liquid ammonium polyphosphate	634	4,090	274	7	1	986	
Dicyandiamide-phosphoric acid-formaldehyde (pre-reacted)	725	5,100	260	21	4	909	46

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[1] Adjusted to 60 lb/cu ft density.

[2] Values are averages of two tests.

[3] Specimens ⅛-inch thick unless indicated otherwise.

[4] Values for 8-foot tunnel furnace are averages of two tests; values for 2-foot tunnel furnace are averages of four tests.

[5] Products bearing code numbers listed were formulated as commercial fertilizers; the numbers refer to percent assay of nitrogen, phosphate, and potash, respectively.

[6] THPC means tetrakis (hydroxymethyl) phosphonium chloride.

[7] THPOH means tetrakis (hydroxymethyl) phosphonium hydroxide.

[8] MDP means melamine dicyanidiamide phosphoric acid.

[9] Contained 15 percent fire-retardant chemical and no phenolic resin.

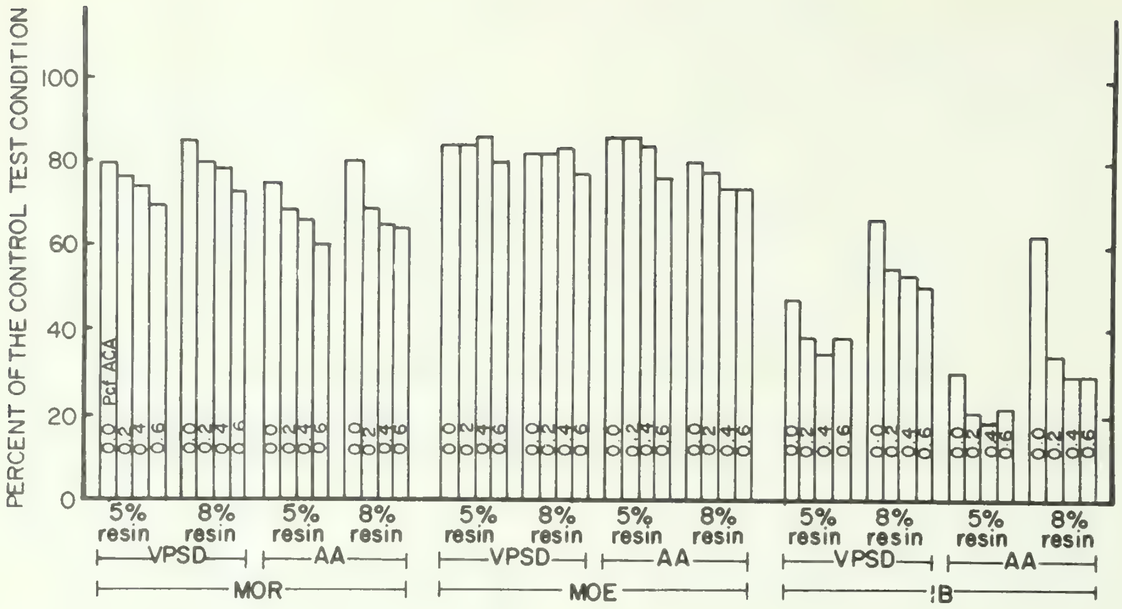

Figure 14.—*Average modulus of rupture, modulus of elasticity and internal bond values following exposure to vacuum-pressure-soak-dry (VPSD) and accelerated aging (AA) conditions, as percents of their control condition values. Samples were from ACA-treated phenolic-bonded particleboard manufactured from flakes of Ghanaian hardwood species. (Drawing after Hall and Gertjejansen 1978).*

Table 28.—*Condition of particleboard stakes from mixed Ghanaian hardwoods after 1 year's exposure in the Caribbean National Forest of Puerto Rico*[1]

Retention of ammoniacal copper arsenate	5 percent phenolic resin		8 percent phenolic resin	
	Decay	Termite	Decay	Termite
pounds/cu ft	*ratings*[2]			
0	49	86	87	91
0	46	89	77	92
.2	86	96	92	100
.2	91	100	90	98
.4	97	100	100	100
.4	100	99	100	99
.6	100	100	100	100
.6	100	100	100	100

[1] Laundrie, J. F., G. C. Myers, and L. R. Gjovik. 1980. Evaluation of particleboards and hardboards from mixed Ghanaian hardwoods after a one-year exposure in the Caribbean National Forest of Puerto Rico. U.S. For. Prod. Lab., U.S. Dep. Agric. For. Serv., Madison, Wis. Interoffice Rep. prepared by the Univ. Minnesota. 20 p.

[2] Ratings based on a perfect score of 100.

boards; but within the former, there was a trend toward a direct relationship between swelling and retention. A similar trend was evident for irreversible thickness swelling and irreversible linear expansion.

The condition of 3¼- by 18-inch stakes cut from these phenolic-bonded particle board panels and exposed for one year in a test plot in Puerto Rico is shown in table 28. All treated stakes, including those containing the lowest retention of preservative, sustained little or no decay and termite damage following exposure. Controls suffered substantial decay damage, but those bonded with 8 percent resin had much less damage than those bonded with 5 percent resin. Results with fiberboard specimens treated and exposed in the same manner as that for the particleboard specimens were very similar.

Internal bond losses of specimens after field exposure were reported by the authors to parallel those induced by the vacuum-pressure-soak-dry test. Reductions in internal bond attributable to exposure averaged 62 and 45 percent for 5 and 8 percent resin levels, respectively. The magnitude of the reductions appeared to be related to preservative retention only in the case of specimens containing 8 percent resin.

Beal[7] studied the efficacy against termites of insecticides applied at several concentrations in the glue of plywood, particleboard, and hardboard by exposing them in southern Mississippi and in the Panama Canal Zone. Chlordane at 0.05, 0.10, and 0.20 percent, and heptachlor at 0.02, 0.05, and 0.10 percent protected all three materials from subterranean termites over 4 years. The higher levels also prevented damage by drywood termites in laboratory tests.

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[7] Beal, R.H. 1980. Final office report summary FS-SO-7.303, Southern Forest Experiment Station, U.S. Dep. Agric. For. Serv., Gulfport, Mississippi.

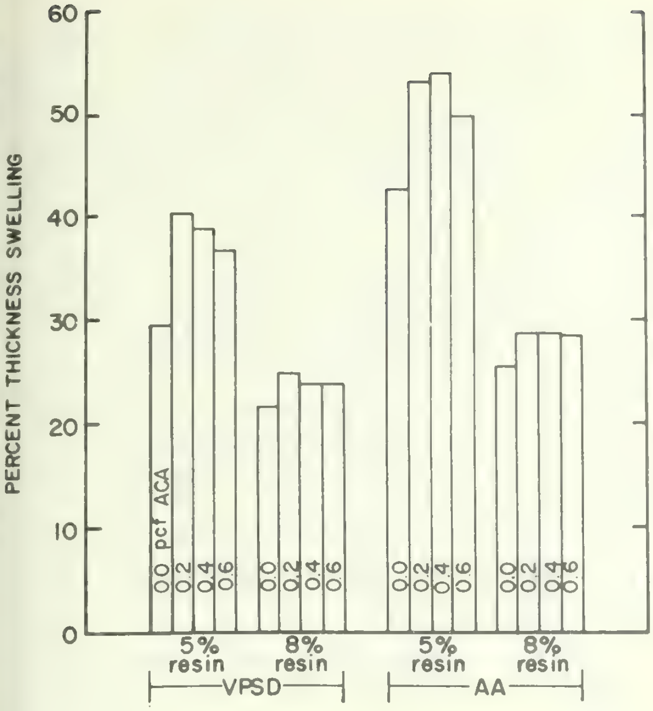

Figure 15.—*Average percent thickness swelling values for test samples similar to those in figure 14. (Drawing after Hall and Gertjejanson 1978.)*

LITERATURE CITED

Akhtar, M. A., and C. S. Walters.
1974. High-pressure treatment of white oak and red oak. *In* Proc. Seventieth Annual Meet. of the Amer. Wood-Preservers' Assoc., vol. 70, p. 209-234. St. Louis, Missouri.

American Wood Preservers' Association.
1977. Book of standards. Amer. Wood Preservers' Assoc., Washington, D. C.

American Wood Preservers' Association.
1978. Wood preservation statistics, 1977. Proc., American Wood Preservers' Association 74:285-323.

American Wood Preservers' Association.
1980a. Crossties—Pressure treated. Standard C6-80. *In* Book of Standards. Amer. Wood Preserv. Assoc., Washington, D.C.

American Wood Preservers' Association.
1980b. Posts—pressure treated. Standard C5-80. *In* Book of Standards. Amer. Wood Preserv. Assoc., Washington, D.C.

Anonymous.
1955. The value of incising for creosote treatment of wooden products. Wood Ind. 10(4):175-176.

Anonymous.
1960. Fence posts service life tests. Coordinated Wood Preservation Council. Group Rep. No. 3, Tennessee Valley Authority, Norris, Tenn.

Anonymous.
1978. Directions for making fire-retardant particleboard bonded with UF resins. Bulletin SB-96, Borden Chemical Co., New York. 6 p.

Arsenault, R. D.
1964. Fire-retardant particleboard from treated flakes. For. Prod. J. 14(1):33-39.

Aston, D., and R. W. Watson.
1976. The performance of preservative treated hardwoods in ground contact. Pap. 3 *In* BWPA Ann. Conv. Proc. 1976:41-57. British Wood Preservers' Assoc.

Baechler, R. H., Chairman.
1947a. Report of Committee 4—Preservatives. *In* Proc., Amer. Wood Preservers' Assoc. 43:58-93.

Baechler, R. H.
1947b. Relations between the chemical constitution and toxicity of aliphatic compounds. *In* Proc., Amer. Wood Preservers' Assoc. 43:94-111.

Baechler, R.H.
1954. Wood in chemical engineering construction. For. Prod. J. 4:332-336.

Baechler, R. H., E. Conway, and H. G. Roth.
1959. Treating hardwood posts by the double-diffusion method. For. Prod. J. 9:216-220.

Baechler, R. H., and H. G. Roth.
1964. The double-diffusion method of treating wood: a review of studies. For. Prod. J. 14:171-178.

Banks, W. B.
1973. Preservative penetration of spruce—close spaced incising an improvement. Timber Trades J. 285:51-53.

Behr, E. A.
1964. Preservative treatment of posts with dry chemicals. For. Prod. J. 14:511-515.

Behr, E. A., I. B. Sachs, B. F. Kukachka, and J. O. Blew.
1969. Microscopic examination of pressure-treated wood. For. Prod. J. 19(8):31-40.

Belford, D. S., and J. Nicholson.
1968. Emulsion additives: A new concept in copper-chrome-arsenate treatment. *In* Proc., British Wood Preserving Assn. 1968:69-101.

Belford, D. S., and J. Nicholson.
1969. Emulsion additives for CCA preservatives to control weathering. *In* Proc., Amer. Wood-Preservers' Assoc. 65:38-51.

Bellman, H.
1968. Pretreatment of wood for pressure impregnation. J. Inst. Wood Sci. 21:54-62.

Bergin, E. G.
1962. The gluability of fire-retardant-treated birch veneer. Can. Dep. For., For. Prod. Res. Branch, Rep. 191. 23 p.

Bergman, O.
1977. Factors affecting the permeability of hardwoods. A literature study. Meddelande, Svenska Träskyddsinstitutet No. 126, 57 p.

Bescher, R. H.
1977. Creosote crossties. *In* Proc., Amer. Wood Preserv. Assoc. 73:117-125.

Blew, J. O., Jr.
1950. Comparison of wood preservatives in Mississippi post study (1950 progress report). U.S. For. Prod. Lab., Madison, Wis. Rep. No. R1757. 13 p.

Blew, J. O., Jr.
1963. A half-century of service testing crossties. *In* Proc., Amer. Wood-Preservers' Assoc. 59:138-146.

Blew, J. O., Jr.
1966. Performance of treated oak crossties. Crosstie Bull. 47(3): 7-10, 12-18, 20.

Blew, J. O., Jr., M. S. Hudson, and S. T. Henriksson.
1961. Oscillating pressure treatment of 10 U.S. woods. For. Prod. J. 11:275-282.

Blew, J. O., Jr., and W. Z. Olson.
1950. The durability of birch plywood treated with wood preservatives and fire retarding chemicals. *In* Proc., Amer. Wood Preservers' Assoc. 46:323-338.

Bois, P. J., R. A. Flick, and W. D. Gilmer.
1962. A study of outside storage of hardwood pulp chips in the Southeast. Tappi 45:609-618.

Boone, S., L. R. Gjovik, and H. L. Davidson.
1976. Sawn hardwood stock treated by double-diffusion and modified double-diffusion. U.S. Dep. Agric. For. Serv. Res. Pap. FPL 265, 11 p. For. Prod. Lab., Madison, Wis.

Borkin, K., and K. Corbett.
1970. Improvement of capillary penetration of liquids into wood by use of supersonic waves. Wood Sci. Tech. 4:189-194.

Borup, L.
1961. A comparison between creosote oil and Swedish salt preservatives K33 and KP. Timb. Technol. 69(2260):53-55; 69(2261):95-98.

Bosshard, H. H.
1961. On the Taroil-impregnation of railway sleepers from beech- and oak wood with temperatures of 100°C and 130°C—Part I: Microscopical observation of changes in the structure and moisture content of the impregnated woods. Holz als Roh- und Werkstoff 19:357-370.

Brenden, J. J.
1974. Rate of heat release from wood-base building materials exposed to fire. U.S. Dep. Agric. For. Serv. Res. Pap. FPL 230, 16 p. For. Prod. Lab., Madison, Wis.

Buckman, S. J., and L. W. Reese.
1938. Effect of steaming on the strength of southern yellow pine. *In* Proc., Amer. Wood Preservers' Assoc. 34:264-300.

Burdell, C. A., and J. H. Barnett, Jr.
1969. Pilot plant evaluation of shock-wave pressure treatments. *In* Proc., Amer. Wood Preservers' Assoc. 65:174-190.

Burkhardt, E. C., and F. C. Wagner, Jr.
1978. End treatment of hackberry logs to prevent blue stain. For. Prod. J. 28(1):36-38.

Carpenter, B. E., Jr., and T. P. Bouler.
1962. Hardwood fence posts give good service. Agric. Exp. Stn. Inf. Sheet 782, 2 p. Miss. State Univ., State Coll., Miss.

Cech, F. C.
1971. Tree improvement research in oak species. *In* Oak symp. proc., p. 55-59. U.S. Dep. Agric. Northeast. For. Exp. Stn., Upper Darby, Pa.

Cech, M. Y., and D. R. Huffman.
1972. Dynamic compression results in greatly increased creosote retention in spruce heartwood. For. Prod. J. 22(4):21-25.

Chudnoff, M., and E. Goytia.
1967. The effect of incising on drying, treatability, and bending strength of posts. U.S. Dep. Agric. For. Serv. Res. Pap. ITF-5. 20 p.

Collister, L. C.
1955. Experience with hickory ties on the Santa Fe. Cross Tie Bull. 36(11):74-76.

Cook, D. B.
1978. Retention and penetration of pentachlorophenol in four-inch bolts of twenty-two hardwood species cut from southern pine sites. M.S. thesis Miss. State Univ., Mississippi State. 79 p.

Cooper, P. A.
1976. Waterborne preservative-treated railway ties—an annotated bibliography. Can. For. Serv. Inf. Rep. VP-X-143, 12 p. Western For. Prod. Lab., Vancouver, B. C., Can.

Côté, W. A., Jr.
1963. Structural factors affecting the permeability of wood. J. Poly. Sci. Part C(2):231-242.

Davis, W. H., and W. S. Thompson.
1964. Influence of thermal treatments of short duration on the toughness and chemical composition of wood. For. Prod. J. 14:350-356.

Dickinson, D. J., N. A. A. Sorkhoh, and J. F. Levy.
1976. The effect of the microdistribution of wood preservatives on the performance of treated wood. *In* Proc., British Wood Preserv. Assoc., Cambridge, June 29-July 2.

Eddy, A. A., and R. D. Graham.
1955. The effect of drying conditions on strength of coast-type Douglas-fir. For. Prod. J. 5(4):226-229.

Ellwood, E. L.
1956. Preservative treatment for Australian rail sleepers. Commonwealth Engineer, Melbourne, 44(1):6-10.

Ernst, K. E. B.
1964. Uber die Impragnierbarkeit einheimische Nadel- und Laubhölzer mit Steinhohlen- Teeröl. Schweiz. Anstalt für das Forstliche Versuchswesn Mitt. 40 (2):187-244.

Eslyn, W. E.
1973. Propionic acid—a potential control for deter-

ioration of wood chips stored in outside piles. Tappi 56(4):152-153.

Franciosi, G. F.
1956. Effect of incising beech cross ties. For. Prod. J. 6:264-270.

Franciosi, G. F.
1967. Behavior of incised beech crossties in track. For. Prod. J. 17(2):48-50.

Furnival, G. M.
1954. Study cold-soaking treatment of posts of Delta hardwoods. Miss. Farm Res. 17(8):5.

Gilbert, W. E.
1962. Fire-retardant testing of particleboard. Tech. Serv. Rep., Reichhold Chemicals, Inc.

Gjovik, L. R., and R. H. Baechler.
1968. Field tests on wood dethiaminized for protection against decay. For. Prod. J. 18(1):25-27.

Gjovik, L. R., and H. L. Davidson.
1975. Service records on treated and untreated fenceposts. U. S. Dep. Agric. For. Serv. Res. Note FPL-068. 45 p. For. Prod. Lab., Madison, Wis.

Gjovik, L. R., and H. L. Davidson.
1979. Comparisons of wood preservatives in stake tests (1979 Progress Report). U.S. Dep. Agric. For. Serv. Res. Note FPL-02. 81 p. For. Prod. Lab., Madison, Wis.

Graham, R. D.
1956. The preservative treatment of eight Oregon conifers by pressure processes. *In* Proc., Amer. Wood Preservers' Assoc. 52:118-138.

Graham, R. D.
1980. Boulton drying: A review of its effects on wood. *In* Proc., Amer. Wood Preservers' Assoc., Rep. of Committee T-4: Poles, Appendix C. Vol. 76:85-88.

Graham, R. D., and E. M. Estep.
1966. Effect of incising and saw kerfs on checking of pressure-treated Douglas-fir spar crossarms. *In* Proc., Amer. Wood-Preservers' Assoc. 62:155-160.

Graham, R. D., and R. J. Womack.
1972. Kiln- and Boulton-drying Douglas-fir pole sections at 220° to 290°F. For. Prod. J. 22(10):50-55.

Greaves, H., and J. E. Barnacle.
1970. A note on the effect of microorganisms on creosote penetration in *Pinus elliottii* sapwood and *Eucalyptus diversicolor* heartwood. For. Prod. J. 20(8):47-51.

Greaves, H., and J. F. Levy.
1978. Penetration and distribution of copper-chrome-arsenic preservative in selected wood species. 1. Influence of gross anatomy on penetration, as determined by X-ray microanalysis. Holzforschung 32(6):200-208.

Hall, H. J., and R. O. Gertjejansen.
1978. An evaluation of the weatherability of phenolic bonded flake-type particleboard from ammoniacal copper arsenite (ACA) treated Ghanaian hardwood flakes. AID Project No. TA(AG)03-75, Dep. For. Prod., Univ. Minnesota, St. Paul. 13 p.

Hallock, H., and E. Bulgrin.
1972. Stabilization of hard maple flooring with polyethylene glycol 1000. U.S. Dep. Agric. For. Serv. Res. Pap. FPL 187, 8 p. For. Prod. Lab., Madison, Wis.

Harkom, J. F.
1932. Experimental treatment of hardwood ties. *In* Proc., Amer. Wood Preservers' Assoc. 28:268-282.

Harkom, J. F., and G. H. Rochester.
1930. Strength tests of creosoted Douglas-fir beams. Circ. 28, Dep. Interior, Canada, For. Serv. 14 p.

Hatfield, I.
1959. Research needed on major problems in wood preservation. For. Prod. J. 9(5):26A-29A.

Hedley, M. E.
1973. Service tests of softwood railway sleepers in New Zealand. Reprint No. 675, New Zealand For. Serv. 2 p.

Henningsson, B.
1974. NWCP field test No. 1 with preservatives applied by pressure treatment. Results after 5 years. Information, Nordiska Traskyddsradet No. 6, 18 p.

Henningsson, G., T. Nilsson, P. Hoffmeyer, H. Friis-Hansen, L. Schmidt, and S. Jakobsson.
1976. Soft rot in utility poles salt-treated in the years 1940-1954. Meddelande, Svenska Traskyddsinstitutet, No. 117E. 137 p.

Henry, W. T.
1970. Effect of incising on the reduction of serious checking in incised vs. unincised hardwood crossties. *In* Proc., Amer. Wood Preservers' Assoc. 66:171-178.

Hong, H.-M., R. S. Smith, L. Paszner, and P. E. Jurazs.
1978. Decay resistance of some brominated and nonbrominated hardboards. Material und Organismen 13(3):223-239.

Hopkins, W. C.
1951. Cottonwood posts difficult to treat. Inf. Sheet 465, Mississippi State College, Agric. Exp. Stn., State College, Miss. 1 p.

Howe, J. P., and P. Koch.
1976. Dowel-laminated crossties. Performance in service, technology of fabrication, and future promise. For. Prod. J. 26(5):23-30.

Huber, H. A.
1958. Preservation of particleboard and hardboard with pentachlorophenol. For. Prod. J. 8:357-360.

Hudson, M.S.
1949. Vapor-drying of oak cross ties. *In* Proc. Amer. Railway Eng. Assoc. 50:403-418.

Hudson, M. S.
1951. Hickory for cross ties: Vapor drying of hickory ties. Cross Tie Bull. 32(11):5-7.

Hudson, M. S.
1954. Cross ties can help in solving the hickory

problem. Railway Purchases and Stores 47(12): 76-78.

Huffman, J. B.
1958. Kiln-drying of southern hardwood crossties. For. Prod. J. 8(6):165-172.

Hulme, M. A., and J. A. Butcher.
1977. Soft-rot control in hardwoods treated with chromated copper arsenate preservatives. Material und Organismen 12(2):81-95.

Isaacs, C. P., E. T. Choong, and P. J. Fogg.
1971. Permeability variation within a cottonwood tree. Wood Sci. 3:231-237.

James, R. E.
1961. A preliminary experiment with high pressure preservative treatments. Proc., Amer. Wood Preservers' Assoc. 57:108-114.

Johanson, R.
1975. Arsenical diffusion treatment of *Eucalyptus diversicolor* rail sleepers. Holz-forschung 29:187-191.

Johnson, B. R., and G. E. Gonzalez.
1976. Experimental preservative treatment of three tropical hardwoods by double-diffusion processes. For. Prod. J. 26(1):39-46.

Johnson, W. P.
1964. Flame-retardant particleboard. For. Prod. J. 14:273-276.

Jurazs, P. E., and L. Paszner.
1978. Fire-retardant treatment of hardwoods—mechanical and physical properties of slurry brominated hardboards. Wood Sci. 10:128-138.

Kanehira, Y., and T. Taniguchi.
1960. Studies on preservative treatment of Itajii (*Pasania Sieboldii* Makino) ties. Wood Ind. 15(8): 16-21.

Kass, A. J.
1975. Effect of incising on bending properties of redwood dimension lumber. U.S. Dep. Agric. For. Serv. Res. Pap. FPL 259, 8 p. For. Prod. Lab., Madison, Wis.

Kozlik, C. J.
1968. Effect of kiln temperatures on strength of Douglas fir and western hemlock dimension lumber. Report D-11, For. Res. Lab., Oregon State Univ., Corvallis. 20 p.

Krzyzewski, J.
1969. Durability data on treated and untreated railway ties. Pub. No. 1113, Dep. For., Canada. 53 p.

Krzyzewski, J.
1973. Performance of diffusion treated railway crossties. Cross Ties 54(9):80-86.

Krzyzewski, J. and H. P. Sedziak.
1975. Preservation and performance of fence posts. Can. For. Serv. Rep. OPX82E, 30 p. East. For. Prod. Lab., Ottawa, Can.

Krzyzewski, J., and B. G. Spicer.
1974. 34 years of field testing of fence posts—results of final inspection. Can. For. Serv. Rep. OPX95 17 p. East. For. Prod. Lab., Ottawa, Can.

Kubinsky, E.
1971. Influence of steaming on the properties *Quercus rubra* L. wood. Holzforschung 25:78-8

Kulp, J. W. (Chairman).
1961. Report of Committee U-5, Post Service Record *In* Proc., Amer. Wood Preservers' Assoc. 57:54 76.

Kulp, J. W. (Chairman).
1966. Report of Committee U-5, Post Service Record *In* Proc., Amer. Wood-Preservers' Assoc. 62:60 130.

Lan, S. T., and H. N. Rosen.
1978. Effect of the addition of waxes to wood-polyme composite. For. Prod. J. 28(2):36-39.

Levi, M. P., C. Coupe, and J. Nicholson.
1970. Distribution and effectiveness in *Pinus* sp. o a water-repellent additive for water-borne woo preservatives. For. Prod. J. 20(11):32-37.

Levy, C. R.
1978. Soft rot. Proc., Amer. Wood Preservers' Assoc 74:145-164.

Levy, J. F., and H. Greaves.
1978. Penetration and distribution of copper-chrome arsenic preservative in selected wood species. 2. Detailed microanalysis of vessels, rays, and fibers. Holzforschung 32(6):209-213.

Liese, W.
1957. The fine structure of hardwood pits. Holz als Roh- und Werkstoff 15:449-453.

Liese, W., and G.-A. Peters.
1977. On probable causes of soft-rot attack of CCA-impregnated hardwoods. Material und Organismen 12(4): 263-270.

Lindgren, R. M.
1930. Preliminary experiments on control of sapstain and mold in southern pine and sap gum by chemical treatment. Lumber Trade J. 97(9):25-26.

Lindgren, R. M., T. C. Scheffer, and A. D. Chapman.
1932. Recent chemical treatments for the control of sap stain and mold in southern pine hardwood lumber. South. Lumberman 8(87):43-46.

Loos, W. E.
1962. Effect of gamma radiation on the toughness of wood. For. Prod. J. 12:261-264.

Loos, W. E., and J. A. Kent.
1968. Shear strength of radiation produced wood-plastic combinations. Wood Sci. 1:23-28.

Lund, A. E.
1966. Preservative penetration variations in hickory. For. Prod. J. 16(2):28-32.

Luxford, R. F., and J. D. MacLean.
1951. Effect of pressure treatment with coal-tar creosote on the strength of Douglas-fir structural timbers. Report D179g, U.S. Dep. Agric. For. Serv., For. Prod. Lab., Madison, Wis.

MacFarland, H. B.
1916. Tests of Douglas-fir bridge stringers. *In* Proc., Amer. Railway Engineers Assoc. 17 (Part II): 281-467.

MacLean, J. D.
1930. Preservative treatment of Engelmann spruce ties. *In* Proc., Amer. Wood Preservers' Assoc., 26:164-183.

MacLean, J. D.
1951. Rate of disintegration of wood under different heating conditions. *In* Proc., Amer. Wood Preservers' Assoc. 47:155-169.

MacLean, J. D.
1952. Preservative treatment of wood by pressure methods. U.S. Dep. Agric. For. Serv. Agric. Handb. No. 40, 160 p. Washington, D.C.

MacLean, J. D.
1953. Effect of steaming on the strength of wood. *In* Proc., Amer. Wood-Preservers' Assoc. 49:88-112.

McMillin, C. W., and F. G. Manwiller.
(In press.) The wood and bark of hardwoods growing on southern pine sites—A pictorial atlas. Gen. Tech. Rep. SO-29, U.S. Dep. Agric., For. Serv. South. For. Exp. Stn., New Orleans, La.

McQuire, Z. J.
1964. The oscillating pressure method for the impregnation of New Zealand-grown timber. Tech. Pap. No. 44, New Zealand For. Serv., Wellington.

Merz, R. W., and G. A. Cooper.
1968. Effect of polyethylene glycol on stabilization of black oak blocks. For. Prod. J. 18(3):55-59.

Myers, G. C., and C. A. Holmes.
1975. Fire-retardant treatments for dry-formed hardboard. For. Prod. J. 25(1):20-28.

Myers, G. C., and C. A. Holmes.
1977. A commercial application of fire retardants to dry-formed hardboards. U.S. Dep. Agric. For. Serv. Res. Pap. FPL-298, 8 p. For. Prod. Lab., Madison, Wis.

Nethercote, C. H., J. K. Schields, and A. Manseau.
1977. Performance of pallets treated with a zinc salt polymer system. Rep. No. OPX187E, Eastern For. Prod. Lab., Canada, Ottawa. 19 p.

Nicholas, D. D.
1977. Chemical methods of improving the permeability of wood. *In* Wood Technology: Chemical Aspects. I. S. Goldstein, ed. ACS Ser. No. 43:33-46. Amer. Chem. Soc., Washington, D.C.

Nicholas, D. D., and J. F. Siau.
1973. Factors influencing the treatability of wood. *In* Wood deterioration and its prevention by preservative treatments. Vol. II. Preservatives and preservative systems. D. D. Nicholas, Ed. Syracuse University Press, Syracuse, N. Y. p. 299-343.

Olson, G. E., F. J. Meyer, and R. M. Gooch.
1958. Pentachlorophenol and heavy petroleum for the preservative treatment of railway crossties. For. Prod. J. 8(3):87-90.

Perrin, P. W.
1978. Review of incising and its effects on strength and preservative treatment of wood. For. Prod. J. 28(9):27-33.

Purslow, D. F.
1975. Results of stake tests on wood preservatives. Progress Report to 1974. Current Paper No. CP 86/75. Building Res. Establishment, Princes Risborough, England. 30 p.

Putnam, J. A.
1947. Fence posts from bottomland hardwoods. *In* U.S. Dep. Agric. For. Serv. South. For. Notes No. 52, p. 2-3. South. For. Exp. Stn., New Orleans, La.

Radkey, R. B. (Chairman).
1960. Report of Committee U-3, Tie Service Records. *In* Proc., Amer. Wood-Preservers' Assoc. 56:236-237.

Rawson, R. H.
1927. A study of the treatment of six inch by twelve inch Douglas fir beams, covering boiling-under-vacuum-pressure process and influence of incising. *In* Proc., Amer. Wood Preservers' Assn. 23:203-215.

Reese, E. T., and M. Mandels.
1957. Chemical inhibition of cellulases and β-glucosidases. Res. Rep., Microbiol. Ser. No. 17. QM Res. and Eng. Ctr., Natick, Mass. 60 p.

Rosen, H. N.
1974a. Distribution of water in hardwoods: a mathematical model. Wood Sci. and Technol. 8:283-299.

Rosen, H. N.
1974b. Penetration of water into hardwoods. Wood and Fiber 5:275-287.

Rosen, H. N.
1975a. Penetration of two organic liquids into hardwoods. Wood and Fiber 6:290-297.

Rosen, H. N.
1975b. High pressure penetration of dry hardwoods. Wood Sci. 8:355-363.

Rosen, H. N., and C. H. vanEtten.
1974. Fiber saturation point determination of once-dried wood in solvents. Wood Sci. 7:149-152.

Rowell, R. M., and W. D. Ellis.
1979. Chemical modification of wood: Reaction of methyl isocyanate with southern pine. Wood Sci. 12(1):52-57.

Rowell, R. M., and R. L. Youngs.
1981. Dimensional stabilization of wood in use. U.S. Dep. Agric., For. Serv. Res. Note FPL—0243, 8 p. For. Prod. Lab., Madison, Wis.

Scheffer, T. C.
1953. Treatment of bilgewater to control decay in the bilge area of wooden boats. J. For. Prod. Res. Soc. 3(3):72-95.

Scheffer, T. C., and F. L. Browne.

1954. Tests of some superficial treatments of exposed wood surfaces for their protection against fungus attack. J. For. Prod. Res. Soc. 4:131-132.

Scheffer, T. C., and J. W. Clark.
1967. On-site preservative treatments for exterior wood of buildings. For. Prod. J. 17(12):21-29.

Schrader, O. H., Jr.
1945. Tests on creosoted laminated stringers. Eng. News-Record 135(20):80-83.

Selbo, M. L.
1959a. Summary of information on gluing of treated wood. Rep. No. 1789 (rev.), 32 p. U.S. Dep. Agric., For. Serv., For. Prod. Lab., Madison, Wis.

Selbo, M. L.
1959b. Effect of preservatives on block-shear values of laminated red oak over a 3-year period. *In* Proc., Amer. Wood Preservers' Assoc. 55:155-164.

Shen, K. C., and D. P. Fung.
1972. A new method for making particleboard fire-retardant. For. Prod. J. 22(7):46-52.

Shinn, F. S.
1955. A progress report on hickory cross ties. Cross Tie Bull. 36(11):70-72.

Shuler, C. E., J. E. Shottafer, and R. J. Campana.
1975. Effect of gamma irradiation *in vivo* on the flexural properties of American elm. Wood Sci. 7:209-212.

Siau, J. F.
1969. The swelling of basswood by vinyl monomers. Wood Sci. 1:250-253.

Siau, J. F.
1970. Pressure impregnation of refractory woods. Wood Sci. 3:1-7.

Siau, J. F.
1971. Flow in wood. 131 p. Syracuse Univ. Press. New York.

Siau, J. F., G. S. Campos, and J. A. Meyer.
1975. Fire behavior of treated wood and wood-polymer composites. Wood Sci. 8:375-383.

Siau, J. F., and J. A. Meyer.
1966. Comparison of the properties of heat and radiation cured wood-polymer combinations. For. Prod. J. 16:47-56.

Siau, J. F., J. A. Meyer, and C. Skaar.
1965. Wood-polymer combinations using radiation techniques. For. Prod. J. 15:426-434.

Siau, J. F., W. B. Smith, and J. A. Meyer.
1978. Wood-polymer composites from southern hardwoods. Wood Sci. 10:158-164.

Silberman, R. A.
1970. Chip brightness and chip brightness preservation: how they affect pulp. Pulp & Pap. 44(6):67-69.

Skolmen, R. G.
1962. Treating costs and durability tests of Hawaii-grown wood posts treated by double-diffusion. Res. Note 198, 5 p. U.S. Dep. Agric. For. Serv., Pacific Southwest For. and Range Exp. St
Berkeley, Calif.

Skolmen, R. G.
1971. A durability test of wood posts in Hawaii-third progress report. U.S. Dep. Agric., For. Serv Res. Note PSW-260. 4 p. Pacific Southwest F and Range Exp. Stn., Berkeley, Calif.

Smith, H. H., and R. H. Baechler.
1961. Treatment of Hawaiian grown wood posts b the double-diffusion wood preservation proces U.S. Dep. Agric. For. Serv. Res. Note No. 187. 8 p Pacific Southwest For. and Range Exp. Stn Berkeley, Calif.

Sorkhoh, N. A., and D. J. Dickinson.
1976. An effect of wood preservation on the colonization and decay of wood by microorganisms. Mat Und Organism. Supplement (Feb. 1976), p. 287 293.

Sribahiono, U. I., J. N. McGovern, and B. R. Johnson
1974. A procedure for estimating the pressure treatability of hardwoods. Univ. of Wis. For. Res Notes, Note 188, 4 p.

Stamm, A. J.
1967. Movement of fluids in wood—Part I: flow o fluids in wood. Wood Sci. and Technol. 1:122-141

Stamm, A. J.
1970. Maximum effective pit pore radii of the heartwood and sapwood of six softwoods as affected by drying and resoaking. Wood and Fiber 1:263-269.

Surdyk, L. V.
1975. Flame-retardant particle-board and process for making same. U.S. Pat. No. 3,874,990. U.S. Pat. Off., Washington, D.C.

Tamblyn, N.
1973. Soft rot in treated wood. Sixteenth For. Prod. Res. Conf., Melbourne, C.S.I.R.O., Div. Building Res., Australia.

Taras, M. A., and M. Hudson.
1959. Seasoning and preservative treatment of hickory crossties. U.S. Dep. Agric. For. Serv. Hickory Task Force Rep. No. 8, 24 p. Southeast. For. Exp. Stn., Asheville, N.C.

Teesdale, C. H., and J. D. MacLean.
1918. Relative resistance of various hardwoods to injection with creosote. U.S. Dep. Agric. Bull. No. 606, 36 p.

Tesoro, F. O., and E. T. Choong.
1976. Relationship of longitudinal permeability to treatability of wood. Holzforschung 30(3):86-90.

Tesoro, F. O., E. T. Choong, and C. Skaar.
1966. Transverse air permeability of wood as an indicator of treatability with creosote. For. Prod. J. 16(3):57-59.

Tesoro, F. O., O. K. Kimbler, and E. T. Choong.
1972. Determination of the relative permeability of wood to oil and water. Wood Sci. 5:21-26.

Thomas, R. J.

1976. Anatomical features affecting liquid penetrability in three hardwood species. Wood and Fiber 7:256-263.

Thompson, W. S.
1954. End diffusion method of treating fence posts. Circ. 193, Miss. State Coll., Agric. Exp. Stn., State College, Miss. 7 p.

Thompson, W. S.
1962. Gluing characteristics of treated sweetgum veneer. For. Prod. J. 12:431-436.

Thompson, W. S.
1964a. Response of two wood decay fungi to metal-binding compounds. LSU Wood Util. Notes No. 3, 4 p. La. State Univ., Baton Rouge, La.

Thompson, W. S.
1964b. Effect of preservative salts on properties of hardwood veneer. For. Prod. J. 14:124-128.

Thompson, W. S.
1965. Response of *Poria monticola* and *Polyporus versicolor* to aliphatic amines. For. Prod. J. 15: 282-284.

Thompson, W. S.
1969a. Effect of steaming and kiln drying on the properties of southern pine poles. Part I. Mechanical properties. For. Prod. J. 19(1):21-28.

Thompson, W. S.
1969b. Factors affecting the variation in compressive strength of southern pine piling. *In* Proc., Amer. Wood Preserv. Assoc. 65:133-144.

Toole, E. R., and W. S. Thompson.
1973. End-diffusion treated fence posts—after 20 years. Miss. For. Prod. Util. Lab. Inf. Ser. No. 17, 3 p. Miss. State, Miss.

Tschernitz, J. L., E. L. Schaffer, R. C. Moody, R. W. Jokerst, D. S. Gromala, C. C. Peters, and W. T. Henry.
1979. Hardwood Press-Lam crossties: Processing and performance. U.S. Dep. Agric. For. Serv. Res. Pap. FPL-313. 22 p. For. Prod. Lab., Madison, Wis.

Vaughan, J. A.
1954. Controlled-air-seasoning. *In* Proc., Amer. Wood Preservers' Assoc. 50:282-287.

Vaughan, J. A.
1955. Controlled air-seasoning of wood for preservative treatment. For. Prod. J. 5(5):45A-46A.

Verrall, A. F.
1953. Decay prevention in wooden steps and porches through proper design and protective treatment. J. For. Prod. Res. Soc. 3(4):54-60.

Verrall, A. F.
1959. Preservative moisture-repellent treatments for wooden packing boxes. For. Prod. J. 9(1):1-22.

Verrall, A. F.
1961. Brush, dip, and soak treatments with water-repellent preservatives. For. Prod. J. 11:23-26.

Verrall, A. F., and T. C. Scheffer.
1949. Control of stain, mold, and decay in green lumber and other wood products. For. Prod. Res. Soc. 1949 Prepr. 58, 9 p.

Vick, C. B., L. I. Gaby, and R. H. Baechler.
1967. Treatment of hardwood fence posts by the double-diffusion process. For. Prod. J. 17(12):33-35.

Walters, C. S.
1967. The effect of treating pressure on the mechanical properties of wood: I. Red gum. *In* Proc. of the sixty-third annu. meet. of the Am. Wood-Preservers' Assoc., vol. 63, p. 166-186. Washington, D.C.: Am. Wood-Preservers' Assoc.

Walters, C. S., and J. K. Guiher.
1970. Treating gum crossties at high lowry pressure. *In* Proc. of the sixty-sixth annu. meet. of the Am. Wood-Preservers' Assoc., vol. 66, p. 258-259. Washington, D.C.: Am. Wood-Preservers' Assoc.

Walters, C. S., and K. R. Peterson.
1965. Report on Project 331-A. Preservative treatment of fence posts by cold-soaking in pentachlorophenol—fuel-oil solutions. Univ. of Ill. Agric. Exp. Stn. For. Note No. 117, 4 p.

Wood, L. W., E. C. O. Erickson, and A. W. Dohr.
1960. Strength and related properties of wood poles. ASTM Wood Pole Res. Prog. Final Rep., Amer. Soc. Testing Materials, Philadelphia, Pa.

Wood, M. W., K. C. Kelso, Jr., H. M. Barnes, and S. Parkikh.
1980. Effects of the MSU process and high preservative retentions on southern pine treated with CCA-type C. Proc., AWPA 76:22-37.

Zentmyer, G. A.
1944. Inhibition of metal catalysis as a fungistatic mechanism. Sci. 100(2596):294-295.

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THOMPSON, WARREN S., and PETER KOCH.
1981. Preservative treatment of hardwoods: A review. U.S. Dep. Agric. For Serv. Gen. Tech. Rep. SO-35, 47p. South. For. Exp. Stn., New Orleans, La.

This report reviews pertinent information on treatment of 56 American hardwood species with more than a dozen preservatives by pressure and non-pressure methods.

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Southern Forest
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New Orleans,
Louisiana

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A History of Forest Pathology Research in the South and Southeast

Arthur F. Verrall

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A HISTORY OF FOREST PATHOLOGY RESEARCH
IN THE SOUTH AND SOUTHEAST

by

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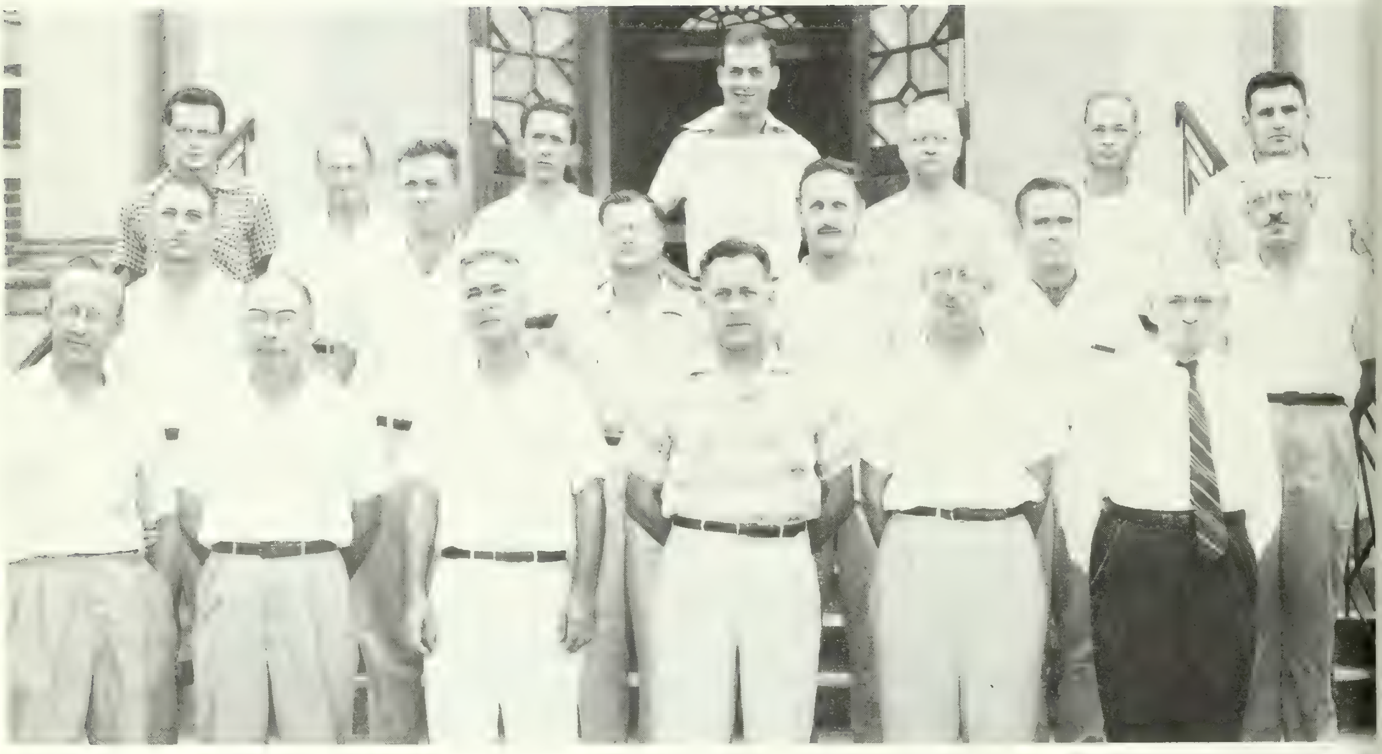
Written under contract with the

United States Forest Service



Forest Pathology Work Conference, Athens, Ga. About 1956

Front row left to right--A.A. Foster, A.F. Verrall, G.H. Hepting, B. Henry, W.A. Campbell, Julian Miller.
Back rows--Stegall, Snyder, E.R. Roth, J.S. Boyce, R.G. McAlpine, E.R. Toole, F. Cobb, B. Zak, L.W.R. Jackson, W.C. Bryan, R. Harrison, G. Thompson, M. Reines.

PREFACE

The development of forest disease research in the South and Southeast and what this research accomplished are recorded in many journal and government publications and in many unpublished reports. Also, much detail about the people doing the research and where and under what conditions it was done exist only in the minds of those involved. This history brings together much of this informaton, particularly for the use of pathologists now engaged in research.

In writing this history, I depended partly on my recollections from 45 years' association with forestry in the South and Southeast and partly on the memories of many of the living pathologists who worked in the South and Southeast. Much information was secured from the Forest Experiment Stations' annual reports and published and unpublished reports. George H. Hepting was particularly helpful in furnishing details about the Southeastern Forest Experiment Station. Also, I drew freely from his "Forest pathology in the Southern Appalachians, 1900-1940" (Hepting 1964). P. C. Wakeley's "A biased history of the Southern Station," which is in typed form only, provided much information on the early work in pathology at the Southern Forest Experiment Station.

Most outstanding forest pathologists have had a forestry background--often with a degree in forestry and advanced training in pathology. This is logical because a true forest pathologist is a forester in that he must have a working knowledge of silviculture and forest management so he can find practical disease controls. There are, of course, specialties in tree disease research in which a plant pathologist without a forestry background can and has made significant contributions to forest pathology. Both groups are represented in research work reported in this history. Also, we cannot ignore the contributions to forest pathology by foresters without specialized pathology training.

In general, I have limited this history to research completed before 1976, even though the results were published later. An exception is the products pathology project at the Southern Station. Research results of this project are included up to its demise in 1979.

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THE SOUTHERN FOREST EXPERIMENT STATION

Before the Southern Forest Experiment Station was established in 1921, forest pathology in the South and Southeast consisted mainly of mycological studies by local, State, and itinerant Federal pathologists. These scientists described a number of forest tree diseases such as brown spot needle blight of longleaf pine and pine rusts. One Federal pathologist, W. H. Long (Office of Investigations in Forest Pathology, Bureau of Plant Industry), conducted field trials on rotting of logging slash in the Ozark National Forest during World War I (Long, 1917). These early pathologists also studied the advance of chestnut blight and white pine blister rust into the Southeast. But there was very little information on the disease picture in southern forests, on the impact of disease on yields, or on possible control measures. So, the South was a research pathologist's paradise in the 1920's and 1930's.

When forest management started in the 1920's, even though only a small portion of the total forest land in the South was involved, foresters and lumbermen began calling for practical control measures--particularly for the control of brown spot in longleaf pine nurseries and sapstain in seasoning lumber. Practical field studies were the logical approach to satisfy this demand, and, as a result, the first 2 1/2 decades of forest pathology research at the Southern Station consisted largely of field studies. The makeshift laboratory space available was used mainly for culturing and microscopic examination of diseased material to determine causal organisms. However, a surprising amount of fundamental information came from these field studies and crude laboratory facilities.

In 1951 the products pathology project got a modern culture laboratory at the Harrison Experimental Forest near Saucier, Miss. In 1961, the tree disease projects got up-to-date laboratory space when the Gulfport, Miss., Forest Sciences and the Stoneville, Miss., Research Center facilities were completed. With gas chromatography and other sophisticated procedures provided, more basic research became feasible on the factors influencing infection, disease development, and the biology of pathogens. This information was needed to refine disease prevention and control measures. At the same time, adequate greenhouse space was provided. However, field trials remained an important tool in establishing the practicality of prevention and control measures and in proving the soundness of many basic concepts established in the laboratory or greenhouse.

Before 1953, the pathologists assigned to the Southern Station were in the Division of Forest Pathology of the Bureau of Plant Industry (BPI) with headquarters in Beltsville, Maryland. The

Bureau was reorganized in 1945 to include Soils and Agricultural Engineering, but I will use the shorter name here. Both tree disease and product pathologists were stationed in New Orleans, La., until World War II when they were transferred to Gulfport, Miss. (products), and nearby Harrison Experimental Forest (pine diseases). Pathologists had been stationed temporarily at Bogalusa, La. (brown spot), and the W. W. Ashe Nursery, Brooklyn, Miss. (nursery diseases). Pathologists of the bottomland hardwood project have all been stationed at Stoneville, Miss., since the project was established in 1952.

Under the Bureau of Plant Industry, the three projects (hardwood diseases, pine diseases, and products pathology) each reported directly to the Beltsville office.

The Beltsville pathologists were familiar with each study of each project; they gave continuous, overall technical supervision, and edited all manuscripts for technical accuracy. This relieved field personnel of almost all administrative duties and resulted in a high research output for each pathologist and a cohesive Nationwide forest disease organization. The only variation in this structure at the Southern Station was from 1947 to 1950 when R. M. Lindgren was transferred from Beltsville to New Orleans where he acted essentially as a division chief, and from 1950 to 1953 when George Hepting supervised the program from Asheville. But direct contacts between the projects and the Beltsville office continued.

After forest pathology was transferred from the Bureau of Plant Industry to the Forest Service in 1953, the Southern Station pathologists were placed in the Division of Forest Management until 1956 when the Division of Forest Disease Research was established with A. F. Verrall as Division Chief. He remained Chief until the Assistant Directorships were established in 1964. As long as Berch Henry was Assistant Director for Diseases, Insects, and Genetics, the three pathology projects received technical coordination from a qualified forest pathologist, but after the Assistant Directorships were assigned on a geographical rather than functional basis, close, continuous technical supervision stopped at the Project Leader. The two pathology projects are now under different Assistant Directors.

When work on brown spot dominated the tree disease research program, the Southern Station's territory included Georgia and Florida as well as Alabama and the other states westward into eastern Texas and eastern Oklahoma. In 1964 Georgia and Florida were transferred to the Southeastern Station and Tennessee to the Southern Station. The Products Pathology Project, however, never was restricted by Station boundaries because, by Washington Office directive, the Southern Station handled most field studies in the southern and southeastern States while the Forest Products Laboratory, Madison, Wis., handled studies for the rest of the country. Often the two units had joint studies covering the entire country and even extending into Central America and the Pacific Islands.

Pine Diseases

Personnel

Paul V. Siggers (Associate Pathologist, BPI) started the pine disease research project in 1928 and remained in charge until his retirement in 1952. The only break was in 1935 when he took 6 months educational leave to complete his doctorate at the University of Minnesota. Siggers was a congenial, quiet man of few words, but a dedicated scientist and a keen observer. He had several temporary field assistants, including F. G. Liming, W. C. Bramble, L. D. Glenn, C. M. Christensen, and A. F. Verrall.

Howard Lamb (Junior Pathologist on Civilian Conservation Corps (CCC) funds) joined Siggers in June 1934. He spent the first few years mainly on hardwood tree problems, but after 1937, helped on the fusiform rust study until his transfer to Columbus, Ohio, in March 1940.

Bailey Sleeth (Assistant Pathologist on CCC funds) helped with the fusiform rust problem from May 1938 to August 1941. Sleeth later joined the Texas Agricultural Experiment Station in the Rio Grande Valley.

R. M. Lindgren (see also Products Pathology) was in New Orleans from 1928 to 1931 and returned in 1947 to work mainly on products studies, but he also helped with the fusiform rust and black root rot studies. He transferred to the Forest Products Laboratory in 1950.

Berch W. Henry (Plant Pathologist) was assigned to the black root rot study at the W. W. Ashe Nursery (Brooklyn, Miss.) in 1948. On Siggers' retirement, Henry assumed leadership of the pine disease project at the Harrison Experimental Forest until 1954 when he became Officer-In-Charge of the Southern Forest Genetics Institute and, in 1964, Assistant Director for Insects, Diseases, and Genetics until his retirement in 1973.

R. P. True (Plant Pathologist) transferred from Morristown, New Jersey, to the Olustee, Florida, Naval Stores Station of the Bureau of Agricultural and Industrial Chemistry in July 1942 to assist the Southern Station with its naval stores project. In January 1949, he went to West Virginia University as Professor of Forest Pathology. His stay at Olustee straddled the transfer of the naval stores project from the Southern to the Southeastern Station.

Paul C. Lightle (Plant Pathologist) directed the pine disease project from 1956 to 1959, after which he transferred to the Rocky Mountain Forest Experiment Station at Albuquerque, New Mexico.

Felix J. Czabator (Plant Pathologist) transferred from the Division of Forest Management Research to Forest Disease Research in 1958 and remained until his retirement in 1977. From August 1960 to February 1961 he was in Yugoslavia under contract with the International Cooperative Administration of the State Department, serving as an advisor on nursery problems. At Gulfport his work was mainly on nursery and rust problems. He was in charge of the pine disease research from 1961 to 1969.

Frederick F. Jewell (Plant Pathologist) was assigned to the Genetics Institute in 1955 and helped with the pathology phases of resistance of pines to rust. In 1966 he resigned to accept a professorship in forest pathology at Louisiana Tech University but continues to cooperate with the Genetics Institute.

Glenn A. Snow (Plant Pathologist) arrived in 1957 and has worked on both brown spot and fusiform rust. He became Project Leader in 1970. His present research is mainly on fusiform rust.

Ronald C. Froelich (Plant Pathologist) joined the project in 1961. He worked mainly on annosus root rot at first but later on fusiform rust.

Albert G. Kais (Plant Pathologist) was assigned to the Project in 1962 and has worked on brown spot and fusiform rust. He is currently working on the brown spot disease.

Charles H. Walkinshaw (Plant Pathologist) worked with the pine disease project from 1962 to 1965, studying tissue culture of *Cronartium fusiforme* and the chemistry of spore germination. For the next few years he was Assistant Professor of Microbiology at the University of Mississippi Medical School but continued to cooperate with the Gulfport group. He returned to the Southern Station in 1968 and was assigned to NASA's Lunar Receiving Laboratory in Texas where he continued some work on fusiform rust. He returned to Gulfport in 1973.

Snow, Froelich, Kais, and Walkinshaw currently are assigned to the pine disease project.

Brown Spot Research Before 1928

Brown spot was described in the 1870's but was not recognized as a major problem until forest fire control became general in the South. Prescribed grass fires remained a common field control method; and before about 1915, intentional or accidental fires annually burned much of the longleaf pine area and presumably kept brown spot within bounds. The first observational research of practical value was by H. H. Chapman (1926), a professor at Yale, who suggested that woods fires controlled brown spot.

In 1928, P. C. Wakeley (Silviculturist at the Southern Station), to check Chapman's contention, established a series of plots near Bogalusa, La., on a severe burn that covered a square mile. In a short time the brown spot fungus was reestablished over the entire burn. But seedlings on the burned area started height growth 3 years earlier than those on adjacent unburned areas--Chapman was right.

Carl Hartley (Division of Forest Pathology Research, Washington Office) advised Wakeley to establish more unburned control plots and to try fungicidal control with Bordeaux mixture and lime sulfur. Wakeley had the Great Southern Lumber Company, Bogalusa, La., spray a series of plots. These studies on brown spot started formal forest disease research in the South and resulted in the assignment of Paul V. Siggers to the Southern Station to start a tree disease research project.

Brown Spot Research, 1928-1952

Siggers took over Wakeley's spraying studies and expanded them to include not only seedlngs in nurseries, but also natural regeneration and plantations. Bordeaux mixture controlled brown spot so well that Bordeaux spraying soon became a standard practice in longleaf pine nurseries.

Most of Siggers' work on brown spot was done by himself or with the aid of temporary field assistants who seldom stayed more than 6 months. The only field assistant who published any results was A. F. Verrall. His two papers on brown spot showed that local disease intensification was mainly by spore dissemination by rain splash, and that temperatures sufficient to kill needles also kill the fungus in them (Verrall 1936) and that resistance of saplings and certain seedlings of longleaf pine is associated with high levels of resin production (Verrall 1934). These studies, of course, reflected Siggers' expert advise.

Research during this period included extensive surveys from South Carolina to Texas that established the hosts, geographic distribution, and economic importance of brown spot in the South. Other field and laboratory research included: resolving the taxonomy of the imperfect stage of the causal fungus and the discovery and naming of the perfect stage (*Scirrhia acicola* (Dearn.) Siggers); the effect of defoliation on seedlings; and the effect of soil fertilization on diseased seedlings. Economic controls were developed, including fungicidal spray schedules for nurseries and plantations and prescribed burning for natural regeneration.

These findings were made available to foresters in journal reports and Station publications. A complete summary was presented in a technical bulletin (Siggers 1944).

Siggers (1950) noted in cultures of *S. acicola*, germtube fusions, hyphal fusions, and the breakup of multicellular conidia at septa. He postulated that these might lead to genetic variations.

Brown Spot Research, 1953-1959

Little research on brown spot was done during this period. However, more commercial interest was being shown in longleaf regeneration, and the Alexandria Research Center had developed better planting techniques. So in 1959, 26 fungicidal spray schedules were tried in plantations and natural regeneration in Louisiana and Alabama. Bordeaux mixture proved more effective than ferbam for field use because of its greater persistence. One spray a year proved insufficient; two a year (Spring and Fall as recommended by Siggers) were adequate; more frequent spraying was most effective but did not justify the added expense. These results were not published.

In constrast to Sigger's report, Berch Henry (1954) found both conidia and ascospores of *S. acicola* were produced every month of the year.

Brown Spot Research Since 1959

Early in this period, aerial and mist-blower applications of cycloheximide derivatives and of Bordeaux mixture were tested in the field in Louisiana and South Carolina. Again, Bordeaux proved more effective because of its longer residual effect. Both aerial and mistblower applications proved satisfactory and practical. No results were published.

Kais (1964) found that cycloheximide semicarbazone in liquid cultures inhibited spore germination of *S. acicola*. The fungus revived, however, when transferred to a chemical-free medium. The cycloheximide derivatives gave adequate temporary control of brown spot but had little residual effect (Snow *et al*. 1964).

Kais (1971) confirmed Henry's report that both conidia and ascospores of *S. acicola* are discharged every month of the year. Spores were more numerous from May through August. Later Kais (1975a) used four new chemical sprays as well as Bordeaux on longleaf pine seedlings in the field. He recommended Chlorothalonil as an alternative to Bordeaux mixture.

Currently Kais' main research is on brown spot in relation to the breeding of resistant longleaf pines. He is studying the environmental and nutritional requirements of *S. acicola* needed to produce adequate amounts of spores for artificial inoculations (Kais 1975) and he also is studying methods for inoculation and incubation of seedlings (see Snow 1961). The latter is of particular importance in a program of screening longleaf for resistance because of the inconsistent results of previous workers.

Snow (1961) found that isolates of *S. acicola* varied widely in culture, but that these differences could not be correlated with pathogenicity, type of symptom, or time of symptom expression. Cultural characteristics also changed with repeated transfers of the fungus on agar. These findings may be explained by Siggers' observations (Siggers 1950).

Longleaf Pine Strains Resistant to Brown Spot

Siggers, Wakeley, and others familiar with longleaf pine regeneration noted that certain individual seedlings apparently were resistant to brown spot, because they remained healthy when close to severely infected seedlings.

In 1928, Wakeley rated 15 of 540 seedlings used in planting as brown-spot resistant, but little use was made of any resistant individuals for three decades; i.e., until Derr and Snyder started their studies of genetic resistance.

In 1937, Siggers found an essentially disease-free 2-year-old longleaf pine seedling in an abandoned nursery. This seedling (called Abe) was transplanted to the Palustris Experimental Forest near Alexandria, La. Harold J. Derr, Silviculturist at the Alexandria Research Center, found that Abe's progeny from wind- and artificial-pollination have a considerable degree of resistance to brown spot, indicating that the resistance is genetically controlled.

E. Bayne Snyder, Geneticist at the Gulfport Genetics Institute, cooperated with Derr and assumed full responsibility for resistance studies when Derr retired in 1976.

Abe and resistant individuals found by Wakeley in 1928 and by others since, gave the geneticists brown-spot resistant parents from Louisiana, Mississippi, Alabama, Georgia, and Florida. Open-pollinated resistant parents yield progeny with adequate resistance, and intercrosses between resistant parents yield highly resistant progeny. So, brown-spot resistant material is easily available with sufficient genetic variability to avoid the dangers inherent in monotypic populations.

Henry and Wells (1967) and others (see Snyder, et al. 1972) found that longleaf pine seed source influences susceptibility to S. acicola. In general, sources from the western part of the range of the longleaf are more susceptible than those from other areas where susceptibility is more variable.

Resistance studies were summarized by Snyder and Derr (1972).

Kais is now working with the geneticists on resistance studies. He is the first pathologist assigned to brown-spot resistance studies.

Wakeley kept very detailed notes on diseases in plantation management studies. He reported (Wakeley 1970) that at age 30 longleaf pine trees classed as lightly infected with brown spot at age 4 produced 1.7 to 2.4 times as much pulpwood as an equal number classed as moderately to heavily infected.

Fusiform Rust

Fusiform rust is one of the most destructive diseases of slash and loblolly pines, particularly on former longleaf pine sites. As long as the resistant longleaf pine predominated on these sites, fusiform rust was not important in forest management. But, with the clearcutting of longleaf stands, two factors made fusiform rust a serious threat: (1) Natural invasion and extensive planting of slash and loblolly pines replaced longleaf over much of its former range, and (2) general fire protection greatly increased the amount of the alternate host--oak--in southern pine forests. As a result, by 1937, fusiform rust was sufficiently prominent that Siggers changed his major research effort from brown spot to fusiform rust.

Fusiform Rust During the Siggers Period

To better evaluate the impact of fusiform rust on different pine species in different parts of the southern pine belt, Siggers, Lamb, and Sleeth extensively surveyed natural stands, plantations, and nurseries.

Nursery spray trials showed that Bordeaux mixture controlled rust in nurseries and observations indicated that pruning infected branches might decrease the number of destructive stem infections. In 1938 nurserymen were advised by mimeographed instructions and personal visits how to recognize infected seedlings so they could be culled during grading and how to spray to prevent infections. CCC camps were visited to acquaint crews with rust symptoms so that worthless infected trees could be removed in sanitation operations and that saplings with only branch infections could be saved by pruning.

Siggers and his assistants also started a comprehensive research program. Lindgren helped after 1947. Studies established:

1. The relative susceptibility of oak species.

2. That infected nursery stock seldom survived in outplantings.

3. Fungicidal spray schedules for nurseries.

4. Temperature requirements for germination of the 4 spore forms and that aeciospores and urediospores remain viable after several months storage at 10°C and for longer periods at 1 to 4°C.

5. The relationship of weather to infection.

6. From tests of slash pine strains from seed collected across the South and from western Cuba, that strains vary in susceptibility, but that geographic source by itself will not yield practical resistance.

7. That a single prescribed burn selectively kills stem-cankered trees and reduces the number of viable branch infections but makes stands more susceptible to future infections.

8. The effect of growth rhythm on the amount of infection. Pines that break dormancy early are most susceptible. Factors promoting early breaking of dormancy were found to be cultivation, soil fertilization, heavy pruning, and seed source.

9. From tests of seedlings whose parents had 0, 1, and 2+ infections and from seed source studies, that genetic resistance does occur but that freedom from rust in nature is a poor indication of resistance, apparently because disease escape complicates the picture.

10. From trials of the dithiocarbamates which became available by 1947, that the ferric form was superior to Bordeaux mixture for rust control in nurseries.

11. That density of planting importantly influences the number of stem infections because close planting promotes early natural pruning before many branch infections reach the stem.

12. That a pulpwood thinning, by opening the stand, greatly increases the number of future infections.

13. That mycelium extends no more than 1/2 inch from visible swellings on seedlings.

Siggers organized Hedgcock's (Beltsville Office) copious notes on the taxonomy, characteristics, hosts, and geographic ranges of the pine oak rusts (Hedgcock and Siggers 1949).

The research findings of Siggers, Lamb, Sleeth, and Lindgren were summarized by Siggers (1955). These findings certainly laid the groundwork for the research that followed.

Fusiform Rust, The Disease Resistance Period

Shortly after Siggers' retirement in 1952, the rust research turned strongly toward studies of genetic resistance for which the pine disease project and the Genetics Institute combined forces. Siggers' studies of geographic seed source and progeny of trees with 0, 1, and 2+ infections clearly showed that variation in susceptibility to fusiform rust exists within the species *Pinus elliotii* and *P. taeda* but the only evidence of practical resistance was in southern Florida slash pine (var. *densa*), which does not have the form and hardiness for commercial use in the longleaf pine belt. A massive screening program would be needed to find suitable rust-resistant strains of the southern pines.

Wakeley's geographic seed source studies indicated that with loblolly pine (unlike slash pine), susceptibility decreases from east to west. Wells (Physiologist, Southern Station) and Switzer (Professor of Forestry, Mississippi State University) found that loblolly from the Florida Parishes of Louisiana exhibits a practical degree of resistance to fusiform rust (Wells and Switzer 1971). The authors speculate that this resistance may exist because loblolly acquired shortleaf pine genes. This possibility is supported by Wakeley's report (Wakeley 1968) that longleaf pines at age 30 in his plantations, showing juvenile resistance to brown spot or showing early height growth, were significantly more susceptible to fusiform rust. Again, this suggests admixtures of genes from the rust-susceptible pine species.

Jewell and coworkers (1964) also showed that resistance is genetically controlled and that some nursery-infected seedlings formed reaction parenchyma and recovered (Jewell and Snow 1972), a process that might also be used in resistance studies.

One of the first needs in a screening program for resistance to fusiform rust was the development of inoculation techniques. Jewell (1960) described a simple system using telia-bearing oak leaves in a humidified tent. Snow and Kais (1972) perfected a system by which regulated amounts of inoculum could be blown onto specific parts of seedlings. This is the precise method needed for the finer research in genetic resistance. Later (see section on the Southeastern Station) a less precise method was developed for mass inoculation of large numbers of seedlings.

Eleuterius (Biological Technician, Gulfport, Miss.) studied the penetration, development, and sporulation of Cronartium fusiforme on water oak Quercus nigra (Eleuterius 1968). In some cases a hypersensitive reaction occurred so that no uredia and telia formed--only yellow spots on the leaves. So variation in susceptibility among water oaks evidently occurs.

Snow and his coworkers conducted research on the production and dispersal of sporidia of _C_. _fusiforme_ and on weather and other factors determining infection rate. Their results were published in 1968 as four articles in Phytopathology Volume 58. These findings greatly increased our knowledge of the epidemiology of fusiform rust.

Extensive screening tests for fusiform rust resistance have been made by both the Southern and Southeastern Stations and also by pathologists and geneticists at several southern state universities. The early work, however, was done at the Southern Station. The first evidence was that resistance could be secured by crossing slash or loblolly pines with the essentially immune shortleaf pine. Henry and Bercaw (Gaylord Container Corp.) reported that shortleaf-loblolly hybrids remained rust-free after 5 years exposure in an area of appreciable rust (Henry and Bercaw 1956). Later tests with artificial inoculations showed that the hybrids, although highly resistant, are not immune.

Strains of loblolly and slash pines have been found that have appreciable resistance to fusiform rust, but further work is needed to establish how practical such resistance is.

Strains of a pathogen, varying in pathogenicity, complicate the control of many plant rusts. The first evidence of such specialization in _Cronartium_ _fusiforme_ was the report by Kais and

Walkinshaw in 1964 of an albino strain of the fungus which is persistent (Kais 1966). Snow and coworkers first reported pathogenic races of _C_. _fusiforme_ in 1969 (Kais and Snow 1972, Snow _et al_. 1975). Such variation is further shown by the finding of greater virulence of inoculum from resistant than from susceptible pines (Snow _et al_. 1976). This finding of physiologic races of _C_. _fusiforme_ greatly complicates developing resistant pine strains, because now they must be tested against many races of the rust. Experience with the cerial rusts raises a further serious question: Do new races of fusiform rust continually develop? The best we can say now is that developing pines resistant to _C_. _fusiforme_ is still far from being solved.

Fusiform Rust, Other Studies

Not all studies after 1952 were on resistance. Researchers also:

1. Produced a guide to thinning. Measurements on rust-killed pines showed that trees with 50 percent or more of the stem cankered probably would not survive until the next thinning and should be removed.

2. Found from field observations that loblolly pine is more susceptible to infection than is slash, but has a lower percentage of infections reaching the stem.

3. Found that in nurseries, basal branching without a swelling is not sufficient evidence of infection to warrant culling.

4. Showed that up to one third of the seedlings in a heavily infected nursery bed can have latent infections that are not detectable at lifting time but will develop on outplanting. This is further evidence of the need for an effective spray program.

5. Devised a rapid differential stain technique for detecting rust mycelium in woody tissue (see Jewell *et al*. 1962).

6. Determined the rate of spread of branch infections (Jewell 1958, Verrall 1961).

7. Found that six non-native pine species are susceptible to fusiform rust (Jewell 1960a).

8. Found from 55 trials of cycloheximide and several of its derivatives showed that these systemics may reduce aecial

fruiting, but are generally ineffective against fusiform rust when applied by dipping roots of infected seedlings before outplanting, spraying nursery seedlings before and after inoculation, spraying the lower boles of infected trees, or spraying wounds where branches were pruned after fungus had just reached the stem. In other tests, three systemics (benomyl, oxycarboxin, and C4-524) used as a soil drench gave only partial control. Recently, another systemic (Benodanil) has shown much more promise in controlling fusiform rust on seedlings (Hare and Snow 1976).

9. Studied tissue changes in rust-infected slash pine seedlings (Jewell *et al*. 1962).

10. Found that telia and uredia can develop on stems of *Q. nigra*. They also can develop on both upper and lower sides of leaves (see Eleuterius and Snow 1964).

11. Found 5-10 percent of nursery infected seedlings alive after 2.5 years with no evidence of living galls (Snow *et al*. 1963).

12. Found that C. fusiforme can be kept alive at least 5 months in cultures of gall tissue from seedlings. Walkinshaw did much of this tissue culture work under contract with the Washington Office while he was at the Medical School and continued it at NASA after his return to the Forest Service.

13. Also studied the physiology of the germination of C. fusiforme spores (Walkinshaw 1965). One study strongly suggested that endoginous reserves may become depleted in stored aeciospores.

14. Wrote a critical review of the literature on fusiform rust--the disease, pathogen, host relationships, and control (Czabator 1971).

Nursery Diseases

Lamb's early work and recent research on hardwood nursery diseases is discussed later under "Hardwood Tree Diseases" and the research on the control of brown spot and fusiform rust in nurseries has been included in the sections under those headings.

Black Root Rot

An undescribed root deterioration of pine seedlings was found in the W. W. Ashe Nursery near Brooklyn, Miss., soon after the nursery was established in 1936. In 1937 Lamb found nematodes associated with the root rot, later named black root rot. Shortly thereafter Lamb and Sleeth isolated *Fusarium* spp., *Torula marginata*, and *Sclerotium bataticola* from diseased roots, and Sleeth showed that the rot was infectious. (None of this information was published).

By 1947, black root rot was causing sufficient reduction in yields at the Ashe Nursery that control became imperative. So, Siggers and Lindgren started soil fumigation trials. The following year Berch W. Henry joined the Southern Station and was assigned full-time to a study of black root rot. During the next 4 years, six fumigants were tried at different concentrations in fall and spring applications. Several fumigants gave adequate disease control but ethylene dibromide and methyl bromide proved best. The carryover effect of fumigation and the survival of diseased seedlings on outplanting also were studied.

Henry failed to produce typical symptoms of black root rot with artificial inoculations with nematodes and fungi isolated from diseased seedlings or with various combinations of the organisms.

An explanation of the etiology of black root rot had to wait further research at the Southeastern Forest Experiment Station. Henry (1953) summarized the Southern Station findings on black root rot.

Although black root rot is primarily a nursery disease, Smalley and Scheer (Research Foresters, Southern Station) reported it in slash pine plantations in the Florida sand hills (Smalley and Sheer 1963).

Miscellaneous Nursery Research

In 1952 Henry tried four seed and seven soil treatments for the control of seed decay and damping-off of longleaf and loblolly pine seedlings. A preplant soil treatment with formaldehyde proved most effective. (No results were published).

In 1964 the Southern Station cooperated with Louisiana State University in a test of soil fumigation at the Southwest Louisiana Nursery near Oberlin. The test was conducted in an area where root diseases and weeds seriously curtailed production and reduced quality of seedlings. Of the four fumigants tried, methyl bromide gave best control of nematodes, weeds, and fungi but could be justified on a basis of cost only where weeds were a major problem (Shoulders *et al*. 1965).

Nursery Extension

Felix Czabator joined the Division of Forest Management at the Southern Station in 1956. Previously, he had been a nurseryman for the State of Alabama and troubleshooter for Mississippi State Nurseries. At the Southern Station he did service work for tree nurseries on Soil Bank Funds. In 1958 he transferred to the Division of Forest Research and continued to advise nurserymen on disease and other problems. Thus, the Station was able to get its expertise on nursery practices to State and Federal nurseries within its territory. This service was discontinued in 1960 when Czabator went to Yugoslavia as an advisor on nursery problems. Currently service work is the responsibility of State and Private Forestry.

Annosus Root Rot

By 1960, timber managers were becoming alarmed by losses from *Fomes annosus*. From what we know now, the reason for this upsurge was obvious. Large acreages of plantations of slash and loblolly pines that were planted on old-field sites in the 1940's had reached the age for thinning.

Southern Station pathologists made a preliminary survey of plantations in 1960 and started an annotated bibliography of the world literature on _Fomes annosus_. The bibliography was started by J. W. Koenigs who also helped with the original survey. He completed the literature review after his return to New York State College of Forestry (Koenigs 1960).

In 1961 the Southern and Southeastern Stations joined forces to make a detailed survey of southern pine forests from Virginia to Texas to appraise the annosus situation. This survey established the main factors contributing to annosus damage: thinning plantations on old field sites, particularly those on deep light soils and those with dense litter (Powers and Verrall 1962). This information was basic to future research on contributing factors and control.

Most later research on annosus root rot was done by Froelich:

1. Based on the finding that deep litter favored annosus damage, tests of prethinning prescribed burning were started in 1963. Burning materially reduced the amount of attack (Froelich _et al_. 1978).

2. Dusting sulfur (2000 lb/acre) appeared to check the spread of *F. annosus* by providing a long-term reduction in soil pH (Froelich and Nicholson 1973).

3. Based on an analysis of the soil in 137 plots with severe, light, or no annosus damage, a formula was devised for assessing annosus hazard by soil factors (Froelich *et al*. 1966).

Other Research

From 1930 to 1934 Siggers tested slash disposal methods in the Ouachita National Forest and found that slash left as it falls rotted fast and was more economical than piling, lopping and scattering, or burning (Siggers 1935).

Dean Weddell (University of Georgia) brought to the attention of pathologists, a new disease of shortleaf pine. Siggers and Doak (1940) described it as "littleleaf disease" of shortleaf pine, but the main research on this disease was done later at the Southeastern Station.

R. P. True, at Olustee, Florida, in addition to his main assignment of histological studies on the effect of acid treating on turpentining, made pathological studies of fungus relationships to turpentining. He reported that some fungi are agents of dry-face (True 1946) and that the pitch-canker fungus prolongs gum flow. This work overlapped the transfer of the Naval Stores Project to the Southeastern Station and is considered more fully in the section on that Station.

Cone rust can damage cone crops of slash and longleaf pines--this is particularly true in open-pollination studies at the Genetics Institute. Jewell (1957) found that bagging pine flowers for controlled pollination prevents cone-rust infections. In 1958-59 the Southern and Southeastern Stations cooperated in ferbam spray trials for cone rust control. Results suggested that a single spray might be adequate, but timing had to be worked out. The Southeastern Station assumed responsibility for future trials.

Normally, heartrot is a minor problem in second growth southern pines because they have little heartwood. However, Lightle and Starr (Miss. State Univ.) found appreciable amounts of *Fomes pini* and *Polyporus schweinitzii* in young slow-growing pines on poor sites (Lightle and Starr 1957). The slow-growing trees had a large amount of heartwood.

Phytophthora cinnamomi was found killing Lawson cypress in the Crown Zellerbach arboretum near Bogalusa, Louisiana (Campbell and Verrall 1963). This work was in cooperation with the Southeastern Station.

Froelich and Snow (1965) noted tipburn and killing of slash pines near electric power substations in southern Mississippi which presumably was due to seepage of urea herbicides used in substations for weed control.

W. F. Mann (Officer-in-Charge, Alexandria Research Center) and coworkers found that the hemiparasite Seymeria cassioides attacks the roots of slash pine, and weakens or kills seedlings (Mann et al. 1971).

Hardwood Tree Disease

Forest pathologists from the U.S. Department of Agriculture's Mississippi Valley Laboratory (St. Louis, Mo.), and later the Washington Office of the Division of Forest Pathology, Bureau of Plant Industry, and local State plant pathologists, made excursions into the bottomland and upland hardwood forests 50 years before the establishment of the formal hardwood disease project at the Southern Forest Experiment Station. In 1907 Hermann von Schrenk published

Bureau of Plant Industry Bulletin 114, entitled "Sap-rot and other diseases of sweetgum." In 1917 W. H. Long published USDA Bull. 496 on "Investigations of the rotting of slash in Arkansas". As far as I can determine, Long's tests were the first forest pathology experimentation in the South.

Early Work at the Southern Station

In 1931 L. O. Overholts, Professor at Pennsylvania State University, spent several months at the Southern Station as a Bureau of Plant Industry field assistant collecting and identifying fungi--mainly heart- and saprot-fungi. He was assisted by Frank Kaufert (Field Assistant, Bureau of Plant Industry). At that time, Overholts was the national expert on the Polyporaceae and his collections gave the Southern Station a good herbarium of decay fungi and their associated decays. Cultures of many of the fungi were obtained, but unfortunately, these cultures have been lost. The fruitbodies and decayed wood remain, but in a deteriorated condition.

During the fungus collection period, Kaufert also obtained data on the incidence of fire damage and associated rot. He reported that a high proportion of immature and mature bottomland hardwoods are fire-scarred and that decay associated with these scars is a major cull factor (Kaufert 1933).

In 1932 George H. Hepting (Field Assistant, Bureau of Plant Industry) studied decay following fire in young Mississippi Delta hardwoods. These studies yielded extensive data on the rate of scar healing, the rate of upward spread of decay, and other information on heartrots. Hepting used this material for his doctoral dissertation at Cornell and also published it (Hepting 1935). Kaufert, who assisted Hepting, conducted some disease studies in the Lake States and then became Dean of the College of Forestry at the University of Minnesota.

In 1934, Howard Lamb (Assistant Conservationist on Civilian Conservation Funds) joined Paul Siggers who was in charge of pine disease research. Lamb was assigned to a study of nursery diseases of black locust, mainly at the Soil Conservation Service nursery at Robson, La. and at the Woodworth, La. State Forest Nursery. Many seedlings were being lost from unknown causes. Non-parasitic troubles, such as damage from heat, drought, and insects, caused much of the loss, but some root rot and damping-off occurred. Lamb tried a number of soil and seed treatments when soil fungi were involved. Lamb also examined eight plantings of Asiatic chestnuts in Mississippi in 1935 and 1936. Deterioration of these plantings from fire, cattle damage, etc. prevented useful findings. After 1935 Lamb worked mainly on pine diseases until he transferred to Columbus, Ohio in 1940.

Formal Research Project

The Southern Station's formal hardwood tree disease project started in 1952 when E. Richard Toole transferred from the Southeastern Station and was assigned to the Stoneville (Miss.) Research Center. From the start, the project primarily was concerned with the diseases of bottomland hardwoods in the Mississippi Delta, because it is here that the large volume of hardwood timber and future potential exists. However, the project has extended studies to the bottomland forests along other rivers and, to some extent, upland hardwoods in forests and to shade trees.

In 1971 the pathology and entomology projects at Stoneville were combined. There are administrative advantages to such combined projects, but technical direction is likely to suffer because the Project Leader is proficient in one field only. This is particularly true now that the Assistant Directors are assigned on a geographic basis and do not provide the technical direction obtained with the previous Divison Chiefs.

Personnel

E. Richard Toole, like Paul Siggers, is a quiet, dedicated research scientist who, with little fanfare, personally turned out an enormous amount of information and directed the research of assistants when he was fortunate enough to have them. Toole always had a free hand in selecting and carrying out studies. He remained Project Leader until his retirement in 1969. After retirement, he continued work on decays of wood products at the Forest Products Utilization Laboratory at Mississippi State University.

Theodore H. Filer joined the project in 1963, originally to study mycorrhizae associated with hardwoods. After Toole's retirement in 1969, Filer was in charge of the pathology studies at Stoneville. In 1971 the pathology and entomology projects were combined. In 1974 Filer was appointed Leader of this unit.

F. I. McCracken was assigned to the project in 1967 to continue Toole's work on heartrots. McCracken has worked principally on the biology of decay fungi.

Research Results

Toole's main published contributions were:

1. Decay after fire injury in southern bottomland hardwoods (Toole 1959). This publication includes practical directions for estimating the amount of rot present in different species and its expected rate of spread.

2. Rot entrance through dead branches of southern bottomland hardwoods (Toole 1961). Practical instructions are given for estimating the amount of rot present and rate of spread in different species.

3. Deterioration of logging slash in the South (Toole 1965a). The rate of deterioration as influencing salvage of top wood, and fire hazard for different species logged in different seasons are included.

4. Toole and W. M. Broadfoot (soils expert) showed that sweetgum blight is more severe on poor sites, particularly where high contents of sodium and potassium reduce available water (1959) and that irrigation will alleviate symptoms (1959a).

Some may believe that this list of Toole's major contributions is too restricted. True, he had made important conributions in the Southeast before coming to the Southern Station, and his many studies at Stoneville on cankers, sweetgum lesion, and several other diseases listed later were significant. Certainly, Toole was one of the Station's research leaders, when considering the volume and quality of his research.

Up to 1961, Toole had no real laboratory or greenhouse space, and consequently, his studies were almost entirely field investigations. In 1961, when modern laboratory and greenhouse facilities were completed at Stoneville, studies on the physiology of pathogens and the role of mycorrhizae were possible.

Filer and Toole (1966) found that a number of basidiomycetes and ascomycetes were associated with mycorrhizae of sweetgum and oaks. Filer (1975) reported that yearly winter and spring flooding did not alter the kinds of ecto- and endomycorrhizae of sweetgum and oaks and only temporarily reduced populations of soil fungi. Filer, also studied disease control in nurseries, and developed controls for septoria canker of cottonwood (Filer et al. 1971). A beginning was made in genetic resistance to diseases in hardwoods when Cooper and Filer (1976) found that 10 of 320 cottonwood clones tested were resistant to septoria leaf spot. Many other nursery diseases have been studied. Filer (1973) developed new information on the use of tetracycline systemics to suppress elm phloem necrosis, including time of application, rates, and methods of injection. An inexpensive pressure apparatus was developed to inject chemicals into trees (Filer 1973a).

Toole, Filer, and McCracken have made many other contributions, including new occurrences of disease, describing new diseases, and lesser research findings. Some of these are:

1. *Polyporus zonalis* on hackberry in Alabama.

2. *Clitocybe tabescens* decline of elm and water oak.

3. Sycamore anthracnose.

4. Cephalosporium wilt of elm.

5. Wetwood in cottonwood.

6. *Pythium sylvaticum* root rot of several species.

7. *Corticium galactinum* root rot of several species.

8. *Polyporus lucidus* root rot.

9. *Fusarium solani* stem canker of oak, tupelo, cottonwood, and yellow-poplar.

10. *Colletotrichum gleosporioides* on leaves and twigs of dogwood.

11. *Botryosphaeria ribis* lesions on sweetgum (Toole 1963).

12. Decay following increment borings (Toole and Gammage 1959).
13. Rate of decay in relation to height in the tree based on inoculation tests (Toole 1964).
14. Decay hazard after thinning sweetgum sprout clumps (Toole 1965).
15. Effect of methyl bromide on hardwood mycorrhizae (Filer and Toole 1968).

Surveys

In 1950, B. W. Henry (Pine Disease Project) and T. W. Bretz (University of Missouri), in cooperation with the Arkansas Resources and Development Commission, made a survey of oak wilt in Arkansas and found wilt in six northern counties. In 1958 and 1959, Toole, Verrall (Chief, Division of Forest Disease Research), and P. C. Lightle (Pine Disease Project Leader) made aerial and ground surveys of Arkansas and eastern Oklahoma for oak wilt. Three trees were found in Oklahoma--the first wilt reported there--and a few trees in Arkansas in areas previously known to have oak wilt. No buildup had occurred since the first report in Arkansas in 1951 (Verrall et al. 1959). The main oak wilt surveys in the South were, of course, made by the Southeastern Station, and included surveys in the Southern Station's territory.

From casual surveys in Arkansas, Louisiana, Mississippi, Alabama, and Texas, Toole and Lightle (1960) reported that persimmon wilt was not a major problem because it occurred only in open stands of little value except as food for game and had not been reported on timber-producing sites.

Observations on sweetgum blight were made in the Southern Station's territory from 1952 to 1957, mainly by Toole. He perfected his surveys by establishing 41 plots in 6 locations for periodic observations on 2,239 trees. These surveys and research findings clearly showed that sweetgum blight was a response to moisture shortages.

A survey of 26 sycamore plantations in Louisiana, Mississippi, Arkansas, and Tennessee determined the incidence of such diseases as canker, leaf scorch, and dieback (Filer _et al_. 1975).

Products Pathology

By 1918 the southern lumber industry was well aware of severe losses from stain, mold, and decay during the air-seasoning process. This resulted in some early studies of stain control by the Forest Products Laboratory, but no effective fungicides were developed. R. L. Pettigrew and H. M. Knowlton (Forest Products

Laboratory), from 1914 to 1917, tested several chemical dips for stain control at the Great Southern Lumber Company, Bogalusa, La. Nothing better than soda was found. In 1922, Ernest E. Hubert (Assistant Plant Pathologist, Forest Products Lab.) made a survey of stain conditions in Louisiana; and, in 1928, tested different piling methods for air seasoning in Texas, Louisiana, Mississippi, and Arkansas to determine if piling design influenced stain occurrence. None of this early work was published, but it did emphasize the need for solving the sapstain problem.

In 1917, C. J. Humphrey (Bureau of Plant Industry's Office of Investigations in Forest Pathology) described decay conditions in lumber stored at wholesale and retail yards in the East and South. This was an observational study and the recommended controls were based on reasoning rather than research.

In the early 1920's, a number of severe outbreaks of _Poria incrassata_ "dry rot" in southern buildings resulted in a spurt of observational studies of this fungus. C. W. Edgerton (1924) described several cases. C. J. Humphrey (1923) also described a number of _Poria_ cases, and; additional cases were also cited by Humphrey and L. E. Miles (1925). However no real research was involved, and sound economical controls had to wait until research was conducted on this rot problem. In the late 1920's and early

1930's, C. Audrey Richards (Bureau of Plant Industry at the Forest Products Lab.) examined several cases of Poria rot in Florida. She recommended the same controls as given by Humphrey, Miles, and Edgerton--controls so drastic that rebuilding was sometimes preferable.

The start of the formal products pathology research project at the Southern Station was in 1928 when Ralph M. Lindgren (Assistant Pathologist, Bureau of Plant Industry) was assigned to the Southern Station to investigate sapstain control in green lumber and other wood products. The project continued until July 1979 when Amburgey resigned. There are no plans to hire another products pathologist at the Southern Station, thus essentially closing one of the most fruitful projects at that Station.

Shortly after the Products Pathology Project was established at the Southern Station in 1928, the Wood Preservation Section of the Forest Products Laboratory, Madison, Wis., started a field exposure site at the Harrison Experimental Forest, Saucier, Miss. Thousands of treated and untreated stakes and posts have been exposed there to determine average service life. Starting in 1960, T. C. Scheffer (Pathologist at the Forest Products Lab.) also established some exposure tests at the Harrison Forest. None of these studies are discussed in this report--only those Forest Products Laboratory studies jointly conducted with the Southern Station. Considering the Forest Products Laboratory and the Southern Station exposures, there is little doubt that the Harrison Experimental Forest has been one of the world's most extensive field exposure sites for wood products protection.

Personnel

Ralph M. Lindgren directed the products pathology studies from their inception in 1928 until September 1931, when he left New Orleans for further graduate study. After an assignment in tree diseases, a couple of years as Vice President of the Chapman Chemical Company, and a war-time assignment on *Cryptostegia*, he was assigned to the Beltsville Office of the Division of Forest Pathology, Bureau of Plant Industry. He returned to New Orleans in 1947 to direct all the forest pathology projects. In 1950 he transferred to the Forest Products Laboratory, Madison, Wisconsin as a Division Chief. He retired in 1962. Lindgren was one of those unusual researchers who, in addition to plenty of brain power, had the ability to get widespread cooperation from many sources. He had a high degree of dedication and persistence and could take basic approaches to problems without losing sight of the practical side. He was one of the most important forest pathologists of all times, both for his research and for his effect on other workers when he was an administrator.

In 1929 A. Dale Chapman (Agent, Bureau of Plant Industry, Forest Products Laboratory) came south to assist Lindgren. After Lindgren left in 1931, Chapman directed the sapstain studies until early 1933 when he returned north for a few months before resigning to establish the Chapman Chemical Company, one of the most important purveyors of wood-treating chemicals.

Theodore C. Scheffer (Field Assistant, Bureau of Plant Industry) joined the project in January 1930. Except for the 1931-1932 school year, when he was at the University of Wisconsin, he stayed in New Orleans until the fall of 1934 when he went to Johns Hopkins (1934-1935 school year). In 1935 he was assigned to the Forest Products Laboratory from where he cooperated with the Southern Station in many studies and publications. Since retirement in the early 1970's he has been conducting products pathology research at Oregon State University but is still cooperating with the Forest Service with publications. Scheffer is one of the outstanding products pathologists and has contributed many important papers on the practical and basic phases of wood protection.

Ira Hatfield (Field Assistant, Bureau of Plant Industry) joined the sapstain project in September 1934, but resigned in June 1936 to accept a position with a chemical company handling stain-control chemicals.

Arthur F. Verrall (Assistant Pathologist, Bureau of Plant Industry) transferred to New Orleans from the Dutch Elm Disease Laboratory, Morristown, N. J., in 1936. He directed the products pathology studies and in 1956 became Chief, Division of Forest Disease Research but still maintained leadership of the products pathology studies. In 1964, when the Assistant Directors replaced the Division Chiefs, he remained as Project Leader under Washington technical supervision. Verrall retired in 1965 to accept the forest pathology professorship at Stephen F. Austin State University. He continued to cooperate with the Southern Station by completing the Navy studies and writing several papers.

Paul V. Mook (assistant Pathologist, BPI) assisted Verrall from 1942 to 1948, except for the period May to September 1946 when he helped the University of Pennsylvania with its Navy contract to study mold deterioration of many products in the tropics (Panama Canal Zone). He proved invaluable in the sapstain research because of his inventiveness. He devised and constructed or had constructed several pieces of equipment that made tests easier or, in some cases, feasible.

George M. Harvey assisted Lindgren on pulpwood deterioration studies from February 1950 to December 1953 when he transferred to the Pacific Northwest Forest Experiment Station.

William H. Scheld joined the project in 1962 to study protection of pulpwood by continuous water sprays. He left in 1967 on educational leave and, although he never returned, he helped DeGroot to interpret and publish the water-spray data.

Rodney C. DeGroot (Principal Pathologist) joined the project in 1968 as Project Leader. In 1976 he transferred to the Forest Products Laboratory, Madison, Wis.

Terry L. Amburgey joined the project in 1959. When DeGroot left in 1976 Amburgey was transferred to an entomology project but continued to work on products pathology until he resigned in 1979 to accept a professorship at Mississippi State University.

Sapstain

The sapstain project required Federal financing and extensive financial support from the lumber associations; the use of several million board feet of lumber furnished by a number of lumber companies; donation of chemicals by the chemical industry, particularly Dow and DuPont chemical companies; and the donation of many hours of labor by lumber mills. Particular credit is due Roger Simmons, Executive Secretary of the American Pitch Pine Export

Company, for securing financial support. Grover Harrison, Manager of the Louisiana Central Lumber Company, also was very influential in getting support for the project.

Lindgren, Chapman, and Scheffer tested a large number of fungicides in small-scale tests to determine their effectiveness in controlling stain, mold, and decay in green lumber during air seasoning. The most promising were tried in mill-scale tests on full-sized lumber in regular seasoning piles at a number of southern mills. Three chemicals proved so effective that, by 1933, they were on the market under trade names and in general use:

1. Ethyl mercuric chloride for use on all wood species.

2. Sodium tetrachlorophenate for use on hardwoods.

3. Sodium 2-chloro-orthophenyl phenolate which, in mixture with sodium tetrachlorophenate, for use on all species.

In addition to control tests, Lindgren, Chapman, and Scheffer also determined: (1) the fungi causing stain of green lumber; (2) the rate of radial, tangential, and longitudinal spread of stain fungi in wood; (3) the effect of stain on the rate of water loss and water gain; (4) the relative decay resistance of stained and unstained sapgum; and (5) the effect of stain on the strength of wood. In trying to protect logs with sapstain chemicals, they found that bark beetles carried the fungi below the treated surface during the warm months. The same chemicals also gave only marginal protection to seasoning poles and posts prior to pressure treatment. Lindgren and his colleagues also studied methods of applying chemicals at large and small mills, and the handling practices during manufacture and air seasoning that influence the effectiveness of dips. Included were tests of bulk piling treated green lumber, loss of chemicals by rain wash, and delaying dipping after sawing.

Ira Hatfield investigated the dissemination of stain fungi, and found both wind and insects were important disseminators. He also made some chemical dipping trials with ethyl mercuric phosphate, which soon replaced the less effective chloride, and with sodium pentachlorophenate, which was soon marketed by two companies. Hatfield also made further observations on mill practices that influence stain control.

Verrall, after he was transferred from Morristown, N. J., to the Southern Station in 1936, made a few stain-control tests with the help of T. C. Scheffer from the Forest Products Laboratory. No new chemicals were found in these early trials.

All the information on stain, mold, and decay of green lumber, logs, and other green products made through the 1930's was summarized in a technical bulletin by Scheffer and Lindgren (1940). This bulletin remains the "bible" of sapstain and its control except for recent changes in fungicides used.

Further studies by Verrall showed that treated green lumber can be bulk piled safely for at least 2 weeks and still be air-seasoned essentially stain-free. He also secured more extensive information on: (1) the relative importance and seasonal prevalence of stain fungi (Verrall 1939); (2) the fungi associated with treated green lumber (Verrall 1941a); and (3) the dissemination of stain fungi (Verrall 1941). He made a cultural and staining ability comparison of Diplodia natalensis from stained wood and diseased cotton, orange, etc. (Verrall 1942), and described new species of stain fungi cultivated by ambrosia beetles attacking green southern woods (Verrall 1943).

In 1940, the war effort threatened supplies of stain-control chemicals and therefore, the sapstain control work was reopened in 1942.

A series of small-scale and mill-scale tests showed that the use of critical chemicals could be cut in half and effectiveness increased by using mixtures:

1. 1/2-strengths of either mercury or phenate plus borax.

2. 1/4-strengths each of mercury and phenate plus borax.

Tests also showed that the mercurials were differentially adsorbed by wood so that treating solutions tend to weaken with use. These problems were controlled by maintaining high solution levels in vats. Leaching of chemicals by rain was more fully explored and found most troublesome soon after the lumber was dipped and that phenates were more resistant to washing than the mercurials. One test showed that green hickory, ash, oak, dogwood, and sapgum could be adequately protected by sapstain dips for several months during handling and shipment to England. Verrall (1949) found that a number of molds on wood were favored by certain toxicants. These emergency period stain studies were summarized in a Technical Bulletin by Verrall and Mook (1951).

Building Decays

Observations, mainly in Florida, in the early 1930's by C. Audrey Richards (Pathologist, Forest Products Lab.) and L. V. Teesdale (Forest Products Lab.) showed that many unsolved building decay problems existed in the South. As a result, Verrall initiated a study of building decay in 1939. In 1941 he made a survey of defense housing in Texas, Louisiana, and Mississippi to determine the minimum foundation ventilation needed to protect substructure wood. Soil moisture was found more influential than ventilation. These studies, including the effects of ventilation, soil moisture, and soil covers, were continued for several years with observations by the Southern Station from South Carolina to Texas, and similar studies in other parts of the country by pathologists at the Forest Products Laboratory and Beltsville, Maryland. The results were published by the Forest Products Laboratory and Beltsville offices, and were the basis of specifications for ventilation and soil covers in the Minimun Property Standards of the Federal Housing Administration.

On-the-job Preservative Treatments

Early in the building decay studies it became evident that on-the-job applications of preservatives should be useful in protecting wood exposed off the ground but subject to rain seepage. Because little was known of such applications and the Forest Products Laboratory was not inclined to secure the needed information, the Southern Station investigated this problem. In 1944 Verrall started an extensive series of "joint" tests, i.e., wood dipped in or brush-treated with preservatives, was exposed above ground and subject to rain seepage at joints, simulating those in buildings. Several thousand units were exposed over a 10-year period and some were kept under observation for over 15 years. Test variables included: type of preservative, length of immersion, the effect of added water repellents, and the effect of painting treated wood. One test unit, a joint simulating a step rail attached to the side of a newel, has become a standard test unit. In addition to field exposure tests, the factors influencing penetration and absorption of oil-carried preservatives were determined. These studies were summarized in a Technical Bulletin (Verrall 1965).

Decay Associated with Rain Seepage in Buildings

In 1946, Verrall installed tests to determine the factors influencing the decay of wood siding. These studies were made possible by a grant from the Federal Housing Administration. Later, in 1958, under a contract with the Navy's Bureau of Yards and Docks (to be discussed later), further exposures increased the number of experimental siding panels to more than 40, including such variables as: amount of roof overhang, type of sheathing paper, effect of wood sheathing, type of joint of siding to trim, type of siding, effect of preservative dips with and without water repellents, end painting, and effect of eave gutters. This study also included examination of 1,500 buildings in 8 states and the in-place preservative treating of deteriorating siding on actual buildings.

A number of different types of joints and designs used in step and porch rails, in steps, and in porch flooring also were tested. Additional studies included: determining the fungi associated with decay following rain seepage, the physics of water entry into joints, the association of decay and mold fungi, and determining temperatures on the surface and interiors of exposed woodwork. The information on decay associated with rain seepage was published in a Technical Bulletin (Verrall 1966).

Water-Conducting Fungi

Shortly after Verrall came to New Orleans in 1936, C. Audrey Richards (Pathologist, Forest Products Lab.) accompanied him on a trip through Florida to point out the buildings where she had found the water-conducting decay fungus *Poria incrassata*. At that time the recommended control consisted of removal of decayed wood and all sound wood within 2 feet of visible decay because of a belief that the fungus can survive and grow with no water source except the water of metabolism. This drastic treatment was extremely costly. Over the next 25 years, Verrall observed many cases of Poria decay. In each case, he recommended controls, revisited the building after controls were completed to determine if they had been carried out, and made a final inspection at least a year later to determine if control was effective. Information from these cases plus some laboratory and field tests were summarized in a Technical Bulletin (Verrall 1968). The effective simplified control consisted of removing the source of water (usually soil moisture conducted through rhizomorphs) and removing only wood too rotten to support its load. In every case, conducted water was vital and after this source was removed, the fungus died.

Navy Yards and Docks Contract

The contract with the Bureau of Yards and Docks was handled primarily by the Forest Products Laboratory, but about half of the work was done by the Southern Station. In addition to the experiments with siding already discussed, Verrall visited Navy buildings, docks, and other wood structures in Southeastern United States, Panama, Oahu, and Guam. The Navy was furnished a report on conditions at each installation, and many special reports on such subjects as decay hazard in cold-storage and shower rooms, and the covering of defective wood siding with asbestos-cement shingles. Inspections and tests covered a period of about 10 years. Scheffer and Verrall furnished the Navy a detailed manuscript on the protection of wood structures from attacks by fungi and other deteriorating agents, which the Navy used as a basis for a manual on "Wood Preservation." Later, Scheffer and Verrall (1973) published their report in a reduced form.

Included in the Navy studies were some preservative tests with step-rail units and 2- X 2-foot porch flooring units of several wood species exposed in Mississippi, Wisconsin, and Oregon. These were conducted by Verrall, Scheffer, and Harvey, respectively (Scheffer *et al*. 1963). The results of these regional exposures were used by Scheffer as part of the basis for his Climate Index of decay hazard (See Scheffer and Verrall 1973).

Condensation In Air-cooled Buildings

The Navy inspections in addition to previous surveys and experimental studies gave the first evidence of condensation problems associated with air-conditioning by refrigeration (Verrall 1962). It was some time before architects and engineers accepted these findings, but now a condensation hazard is recognized as a result of poor air-conditioning practices.

Ammunition Box Protection

In 1942, Verrall started tests financed by Frankford Arsenal, Army Ordinance. Scheffer (at the Forest Products Lab.) and Leonard Teitell (Chief, Biochemistry Division, Frankford Arsenal) cooperated. Twenty-five hundred M-22 ammunition boxes were exposed in Mississippi, Wisconsin, and the Panama Canal Zone. Test factors included: 16 chemical dips, 4 pressure treatments, effect of water repellents on preservative effectiveness, effect of painting treated wood, effect of uncovered and tarpaulin-covered piles, and effect of soil treatments for termite protection. In addition, at Gulfport, a test of wire-bound hardwood veneer boxes was included and a large number of simulated boxes were used to study miscellaneous factors. The results of these tests were published in three Frankford Arsenal Reports and were summarized by Verrall and Scheffer (1969). A water-repellent preservative dip of ammunition shipping boxes is now standard procedure.

Pulpwood Deterioration

In 1948, Lindgren started an extensive study of the deterioration of pulpwood in the South. He also included in these studies a few tests with poles, posts, and logs. He was assisted by George M. Harvey from February 1950 through December 1953, after which Harvey transferred to the Pacific Northwest Forest Experiment Station. Harvey continued the pulpwood studies after Lindgren left but Lindgren directed the work from the Forest Products Laboratory.

The pulpwood studies were made in cooperation with the Forest Products Laboratory and several pulp companies. The factors studied were: season of cutting, peeled versus rough bolts, the effect of bolt diameter and length, fungicidal sprays, end coatings, and hardwood and pine. Actual pulping tests of some of the stored material were made at the Forest Products Laboratory to determine the effect of deterioration on pulp quality and yield.

Some of the important results (Lindgren 1951, 1953) were: (1) for short storage periods, close piles of long, large diameter, rough bolts during winter deteriorated slowest, (2) for longer storage periods, small peeled bolts in open piles were best, and (3) a spray of pentachlorophenol plus benzene hexachloride in oil protected rough bolts for at least 6 months. Most pine pulpwood and log decay during the first few months of storage was found to be caused by Peniophora gigantea, but later Lenzites saepiaria was dominant.

One of the most important findings of the pulpwood and post studies was that fluorides (as ammonium bifluoride) applied as a water spray, stimulte the mold Trichoderma which inhibits early decay by Peniophora and greatly increases permeability of the sapwood (Lindgren and Harvey 1952). The latter can have beneficial effects in treating with wood preservatives and in certain pulping processes. Later, Verrall (1966) showed that the same mold is commonly associated with Lenzites saepiaria in nature and frequently increases its decay rate.

The pulpwood studies also showed that stain fungi enter through most live branch scars, but only 20 percent of dead branch scars. Stain fungi also enter through ax nicks and bruised areas and, in small-sized pulpwood, stain and decay fungi apparently can penetrate uninjured bark.

Some water-spray trials on rough round pulpwood and sawlog sizes were made by Carpenter and Toole (1963) at the Stoneville Research Center. They found that continuous and intermittant water spray kept hardwood logs free of stain and decay except for stain in hackberry, presumably of chemical origin. Scheld and DeGroot (1971) and DeGroot and Scheld (1973) found that water sprays kept pine bolts stain and decay free but permitted the growth of bacteria and a number of nonstaining fungi that reduced toughness and increased permeability.

Other Research

1. Samples of southern oaks were collected in 1942 for tests of decay resistance as boat wood at the Forest Products Laboratory. Boats were inspected for decay occurrence--a project directed by Carl Hartley at the Beltsville, Md., office.

2. In 1942 and 1943, Verrall helped George Hepting (Southeastern Station) in a survey of possible decay hazard in Army Air Corps wooden training planes. He also made some observations on possible condensation within wooden plane stabilizers at the New Orleans laboratory. This material was published by Hepting (1944) who was in charge of the plane study.

3. DeGroot (1971) reported that Streptomyces inhibits Lenzites saepiaria in agar culture but increases decay rate in soil block tests.

4. DeGroot made a survey in the Mobile, Ala., area to determine the incidence and location of decay in buildings. The findings were essentially the same as reported by Verrall (1966).

Amburgey, in his work:

1. Wrote a series of papers to get the wood protection findings to the using public. Included is a detailed manual on building decay under a contract with Housing and Urban Development (Verrall and Amburgey 1979). This publication

is an expanded version of the manuscript that Scheffer and Verrall were unable to publish. It is the only complete publication on the subject.

2. With DeGroot, established a study of the deterioration of window units subject to rain seepage. A pentachlorophenol water-repellent dip gave good protection; dethiaminizing did not.

3. With the entomologists studied the interaction of decay and termites. The results were reported in four articles in volume 1 of Sociobiology.

4. Compared the relative effectiveness as a wood preservative, of the old type pentachlorophenol and the same material with the dioxines removed (Amburgey 1977).

5. Studied the discoloration of asphalt shingles by an alga and its control with a hypochlorite (Amburgey 1974).

6. Tested techniques in an attempt to improve the current laboratory standard decay tests (Amburgey 1976).

Dissemination of Research Results

Getting research results to the practical users is an important part of research. Because the Products Pathology Project offered unique opportunities along this line, a separate section on dissemination is included here.

Sapstain. By the mid-1930's southern lumbermen were experts in the art of air drying lumber without fungus degrade because: many had first-hand knowledge of protection methods from the mill-scale studies, and Lindgren, Chapman, Scheffer, and Hatfield, by articles in trade journals and lectures at association meetings, kept the industry abreast of new findings.

Building Decay. With periodic reports of practical findings, Verrall informed builders and architects of decay-control methods. He maintained contact with the pest-control industry by publications in their trade journals, by addressing pest-control operators at State meetings, and by giving a course in building decay at their national short course at Purdue University. Lindgren chaired and Verrall was a member of the Building Research Advisory Board's committee to review the Federal Housing Administration's Minimum Property Standards in the 1950's. Thus, they were able to get better decay protection into these national standards. DeGroot chaired and Scheffer and Verrall were members of a similar committee in the 1970's to bring the standards up to date. Amburgey, with his contacts with Housing and Urban Development, prepared or had prepared, a manual on building decay, a slide series on decay, and guides for inspecting buildings for decay.

The Military. The Army Ordinance and Navy contracts permitted Scheffer and Verrall to get better decay-preventive measures into the military use of wood. Contacts were sufficiently high to get at least some of their recommendations into application directives.

SOUTHEASTERN FOREST EXPERIMENT STATION

The Southeastern Forest Experiment Station originally was organized as the Appalachian Forest Experiment Station, but when Georgia and Florida were transferred to that Station from the Southern Station, and West Virginia transferred to the Northeastern Station in 1964, it became the Southeastern Forest Experiment Station.

Forest pathology research at the Southeastern Station has been indelibly stamped by George H. Hepting, who, except for research done as a graduate student with the Northeastern and Southern Stations, spent his entire professional career at the Southeastern Station. During his tenure there, 1933 to 1971, he conducted, directed, or influenced all pathology research in the Southeast and for 3 years in the early 1950's also supervised the projects at the Southern Station. During the last 8 years before retirement in 1971, he was attached to the Washington Office but stationed in Asheville. During these last years, he authored several important publications: (1) The monumental compendium of the diseases of forest and shade trees (Hepting 1971), the most important single book for American forest pathologists; (2) the relationship of climate and climatic changes to forest diseases (Hepting 1971a); and (3) the effect of air pollution on trees (Hepting 1971b). These are more than literature reviews because they reflect Hepting's long research and research directing efforts. Another important activity during this period was his initiation of and perfection of electronic storage and retrieval of the literature on forest tree diseases (Hepting 1967).

Of course, a Hepting never retires--since his official retirement, he has done extensive writing and counseling, reviewed manuscripts for journals and applications for National Research Council grants. Hepting is one of the all-time greats in forest pathology. His dynamic personality has been felt far beyond his official territory, as I can personally attest from my contacts with him over the years. His standing among pathologists and foresters is further shown by the many calls made on him for consultation, not only in the continental United States, but also in such places as New Zealand (1951) and Puerto Rico, Haiti, and St. Croix (1953). He also was adjunct professor at North Carolina State University (1967-1975) and was the first professional forester elected to the National Academy of Sciences.

Early Work

Even more than in the Deep South, the Appalachian Region was frequented by forest pathologists from the North. R. G. Atkinson and Hermann von Schrenk published on fungi and tree diseases of the area before 1900. More detailed surveys were made between 1908 and 1913 by Perley Spaulding, A. H. Graves (1913, 1914), G. G. Hedgcock, W. H. Long (1913), and others. During the next decade (1913-1923), Hedgcock collected extensive data on the rusts inhabiting the leaves, stems, and cones of conifers, with emphasis on untangling their taxonomic complexities. The parts on the pine-oak rusts were later assembled and published with Siggers' aid (Hedgcock and Siggers 1949). Hedgcock also made some collections and observations on heart rots.

In 1924 and 1925, Gravatt and E. P. Marshall (Washington and New Haven offices, Division of Forest Pathology) made a survey of chestnut blight to establish its rate of spread and behavior (Gravatt and Marshall 1926) and Hedgcock, Gravatt, and Marshall (1925) studied *Polyporus schweinitzii* and *Fomes annosus* in coniferous plantations on the Biltmore Estate in North Carolina. Hedgcock, in the late 1920's and early 1930's, made an extensive study of cull in Appalachian hardwoods from New Jersey and Pennsylvania to North Carolina and Tennessee. He was aided, at various times, by temporary assistants (Frank H. Kaufert, A. Dale Chapman, and J. J. McDermott). This study included data on the amount of cull for the principal hardwood species and its variation with tree diameter and age. It established that fire wounds are the major infection courts for butt rot.

Establishing a Forest Pathology Research Program at Asheville

A concerted study of Southern Appalachian tree diseases was started in 1925 with the Appalachian Forest Research Council instrumental in securing the necessary appropriation. C. J. Humphrey (Division of Forest Pathology, Bureau of Plant Industry) was assigned to cooperate with the Appalachian Station in Asheville, N.C., in 1925. He was the first forest pathologist headquartered in the area. Humphrey started a study of the effect of decay on the tannin content of blight-killed chestnut. However, he remained in Asheville less than a year, resigning to accept a position in the Philippines.

From March 1927 until August 1931, Ralph M. Nelson headed the Asheville office of the Division of Forest Pathology. Aided by temporary assistants (Lake S. Gill, Ralph M. Lindgren, E. J. Eliason, and Dow V. Baxter), Nelson completed the chestnut blight studies, particularly the rate of deterioration (Baxter and Gill 1931) and the tannin content of blight-killed chestnuts (Nelson and Gravatt 1929).

Nelson's major effort was on the relationship of blue stain and pine bark beetles. He demonstrated that blue stain fungi can kill pines quickly and contended that beetles were largely vectors only

(Nelson 1934). Nelson (1931) also made one of the first formal studies of decay in southern pines, finding that little occurred under age 90 and that redheart was more prevalent than butt rot. He also studied Nectria canker on yellow-poplar and Asiatic chestnut (Nelson 1940); started a collection of cultures from sporophores of wood rotters to be used in identifying cultures from decayed wood; and made large-scale plantings of Asiatic and hybrid chestnuts.

In August 1931, because of reduced appropriations and Nelson's transfer to the Forest Service, the Asheville Office of the Division of Forest Pathology was closed.

The Civilian Conservation Corps (CCC) Period, 1933-1940

The Asheville Office was reestablished in 1933 with the appointment of George H. Hepting to give advice on tree diseases to State and National CCC Camps in the Southern Appalachians. These camps were established to employ youths to build roads, camps, lookout towers, etc., and to engage in timber stand improvement. It was the disease phases of timber stand improvement that concerned forest pathologists. Much of the funding for this pathology work was provided through the Forest Service.

Personnel

During the CCC period, pathology personnel at the Southeastern Station usually consisted of two pathologists with a third present for short periods.

George H. Hepting was in charge and actively engaged in both the service and research phases.

Franklin D. Liming helped Hepting with the research phases from September 1933 to August 1934 when he left to accept a position at Ohio State University.

Elmer R. Roth joined the program in April 1934 and for many years was one of Hepting's chief assistants. We will meet Roth again later.

M. L. Lohman arrived in 1935 and spent a few years at Asheville working on Atropellis twig canker of pines.

Luther Shaw assisted Lohman during the summer of 1934 on twig canker and then moved to the Southwest to study a somewhat similar canker of western pines.

Between 1938-1940, Bailey Sleeth (Alleghany Forest Experiment Station), Kenneth H. Garren, Locke Craige, and Paul Warlick each spent about a year at Asheville on heartrot studies.

The CCC Program

Starting in May 1933, Hepting visited CCC camps in the Southern Appalachians to advise CCC personnel on handling disease problems in timber stand improvement work. Starting the following year Hepting and Roth visited more than 100 camps and prepared reports and recommendations for camp directors. Hepting wrote a bulletin on tree diseases in relation to stand improvement (Hepting 1946a) which went through several editions and finally was incorporated in a general publication (Jemison and Hepting 1949).

Early in the program it became obvious that there was little practical information on handling diseases in timber stand improvement and that service work must be supplemented by a research program. So, in conjunction with the service work, Hepting initiated an extensive research program. The main research findings of this period are:

1. Fruiting of Nectria and Strumella on cankered trees (Hepting 1941a). Nectria was found to fruit for several years on felled stems, so that cut trees would have to be burned to reduce inoculum. Strumella does not fruit on down logs but will fruit on girdled, standing dead trees.

2. In thinning oak sprout clumps, the rate of healing and danger of decay varies with the size of the removed sprout, method of cutting, and type of crotch (Roth and Hepting 1943).

3. Sprouts arising lowest on oak stumps are least likely to develop rot, but sprouts arising high on stumps tend to become dominant. Therefore, early attention is needed to insure that low-origin sprouts make up a stand (Roth and Hepting 1943a).

During the first few years at Asheville, Hepting also was busy organizing Hedgcock's data on decay in hardwood, adding new material, and preparing it for publication. It was first released in 1935 as three Appalachian Station Technical Notes (No. 13, 14, and 16). Later, it was published as a Technical Bulletin (Hepting and Hedgcock 1937). Included are the relationships of decay to basal and other wounds, tree diameter, age, and stump sprouts; and the rate of healing of basal wounds.

Hepting also reported several other studies:

1. With R. W. Davidson (Beltsville Office) described some leaf and twig diseases of hemlock in North Carolina (Hepting and Davidson 1935).

2. Described and determined the cause of mimosa wilt (Hepting 1939).

3. Published his doctoral dissertation on decay following fire in Mississippi River Delta hardwoods (Hepting 1935). This included the first report of compartmentalization of decay in tree stems, a point later greatly expanded by Shigo at the Northeastern Forest Experiment Station.

4. Organized and published A. D. Chapman's data on decay losses in shortleaf and loblolly pines (Hepting and Chapman 1938).

5. With D. J. Blaisdell reported a protective zone in sweetgum fire wounds (Hepting and Blaisdell 1936).

6. With R. W. Davidson described a new species of Rosellinia causing a leaf and twig disease of hemlock (Hepting and Davidson 1937).

7. With K. H. Garren and P. W. Warlick correlated oak top rot with external factors (Hepting *et al*. 1940).

Lohman proved that *Atropellis tingens*, associated with twig canker of pines, is pathogenic and made a comparison of it with similar fungi from other regions (Lohman *et al*. 1942). Experience, however, has shown that *A. tingens* is not of economic importance on southern pines.

Elmer Roth (1943) found that invisible incipient decay infections in seasoned and unseasoned oak ties and posts increased decay rate in service even though the decay in service was by fungi other than those originally in the oak tree. He also described top rot in hardwoods following snow damage (Roth 1941).

The Littleleaf Period, 1940-1943

The littleleaf disease, first described in 1932, was causing extensive decline of shortleaf pine in the Piedmont Plateau from Alabama to the Carolinas. Because of its distribution, research on it was assigned to the Southeastern Station and, by 1940, littleleaf research became a major effort of that Station.

Satellite Centers and Personnel

During the littleleaf research period, the Asheville staff consisted of Hepting, supervising the pathologists stationwide; Elmer Roth, who continued working mainly on various heartrot and canker problems; John S. Boyce, Jr., and before transferring to Athens, E. R. Toole. Josiah Lowe, on sabbatical leave from Syracuse, spent part of the 1949-50 school year identifying the wood-destroying fungi in the Asheville herbarium (Lowe 1961). Also, in the 1940's William C. Snyder, on sabbatical leave from the University of California, made a taxonomic study of Fusaria causing wilts of mimosa, staghorn sumac, and pitch canker of pines.

Before 1940, pathologists worked out of Asheville but in the 1940's satellite centers were started to place pathologists near the diseases assigned to them. The first satellite was at Athens, Ga. At first the pathologists were housed in the School of Forestry building, but in 1963, a well-equipped building was completed on the campus of the University of Georgia for all the Southeastern Station projects at Athens. This location permitted ready interchange of ideas with the university faculties in plant pathology, forestry, botany, and horticulture. This created a cultural atmosphere conducive to research--in contrast to such relatively isolated centers as Lake City and Gulfport, where cultural atmosphere must come largely from within.

Lyle W. R. Jackson and Thomas S. Buchanan were the first pathologists stationed at Athens, working mainly on littleleaf. Buchanan remained until 1944 when he joined the marines and Jackson resigned in 1946 to accept a professorship in the School of Forestry, University of Georgia.

In 1946 William A. Campbell reported to Athens and was in charge of the littleleaf studies. After 1954, he became the Director's representative for all the Forest Service projects at the Athens-Macon Center. Campbell was primarily a mycologist but also was involved in much of the pathology research. Starting in 1941, he spent two years at the Research Triangle Park as Project Leader for soilborne organisms, which project was moved to Athens in 1963. Campbell retired in 1971 and accepted a professorship at the University of Georgia.

Bratislav Zak reported to Athens in 1947 and was involved in research on littleleaf, cone rust, and mycorrhizae.

E. Richard Toole worked on the control of hemlock twig rust as a summer assistant in 1938. At Hepting's suggestion he selected the biology of the recently-found pathogen of mimosa wilt for his doctoral dissertation at Duke University. In 1941, he returned to the Southeastern Station on a permanent basis to work on the wilts of mimosa, sumac, and oak, and on the littleleaf disease of shortleaf pine. After a short stay at Athens, Toole moved to Alabama Polytechnic Institute, Auburn, Alabama, to establish another satellite center in proximity to serious littleleaf depredations. For a few years, Toole worked there on some of the soil aspects of littleleaf with the help of W. R. Boggess and Professor Ware of Auburn. The fact that both Athens and Auburn were in the Southern Station territory at that time was a minor point, since the Asheville office had assumed full responsibility for littleleaf research, and pathology was in the Bureau of Plant Industry, not the Forest Service. Toole transferred to the Southern Station in 1952.

Early in the littleleaf research, the soils aspects became so obvious that Hepting got permission from Washington to hire a soils expert and, as a result, Otis L. Copeland, Jr. became the first avowedly non-pathologist professional in the Division of Forest Pathology. From 1948 to 1953, Copeland was stationed on the Calhoun Experimental Forest, Union, S.C. where littleleaf was so severe that shortleaf pine seldom grew beyond pulpwood size. With the aid of Robert C. McAlpine, a geology major who later became an Assistant Director of the Southeastern Station, Copeland worked out the major relationships of soils to littleleaf. Similar to Lake City, Union was a temporary specialized location and no pathologists have been located there since 1953.

When Georgia and Florida were transferred to the Southeastern Station in 1946, the research program was broadened to include more southern pine diseases. Included in the transfer was the Lake City, Florida, Research Center where R. P. True was working on the fungal and physiologic disturbances associated with the naval stores industry. True continued these studies until January 1949 when he became professor of forest pathology at the University of West Virginia. Russell B. Clapper completed True's studies (1948-1953) at Lake City and also finished his earlier work on chestnuts resistant to blight. Clapper retired in 1953.

Not all research during the period 1940 to 1953 was on littleleaf. In addition to the naval stores work already mentioned, research included: Sapstreak of sugar maple; a blight of white pine later shown to be an air-pollution problem; the first appearances of *Fomes annosus* as a major pest; oak wilt; needle cast; nursery diseases; a new *Cronartium* stem rust of Virginia pine; and many diseases of minor importance.

During World War II, Hepting investigated discolorations of yellow-poplar aircraft woods and moisture problems in wood airplanes, and Roth investigated wood decay in boats. Roth, an excellent field pathologist, also continued his studies on various phases of heartrots and cankers until 1958 when he transferred to State and Private Forestry in Atlanta.

Near the end of this period George Hepting was assigned by the Bureau of Plant Industry, at the request of the Forest Service, to compile the forest disease section of the Timber Resources Review. He was responsible for assembling all information on disease losses from the Forest Survey cull data from each Region along with data from such special surveys as those for oak wilt, pole blight, littleleaf, and sweetgum blight. These loss figures are valuable not only in setting research needs but also in estimating how much expected timber deficits could be offset by better disease control.

Walter Dwyer worked on *Fomes annosus* in 1948 and 1949.

In addition to Hepting's pathologist, two others spent considerable time in the Southeast. *Bowen S. Crandall*, who was under Washington supervision, had been working in Tennessee on the newly epidemic persimmon wilt and on a root problem of redcedar seedlings which later was shown to be caused by the seed-corn maggot. About 1940, Crandall moved to Athens, Georgia, still under Washington supervision, in connection with chestnut blight and persimmon wilt, and occupied space with L. W. R. Jackson and Thomas S. Buchanan, the latter two under Asheville supervision, working on littleleaf. A couple of years later, Crandall returned to Washington and William A. Campbell was added to the staff and put in charge at Athens. In addition to Bowan Crandall, another Washington pathologist spent considerable time in the Southeast. During the 1930's, 1940's and 1950's, Jesse D. Diller roamed through the southeastern and southern states establishing plots and making observations on Atropellis canker of pines, planting large numbers of oriental and hybrid chestnuts, and studying crawlspace moisture problems in buildings.

Research Since 1953

When the Division of Forest Pathology (Bureau of Plant Industry) was transferred to the Forest Service in 1953, Hepting became Chief of the Division of Forest Disease Research and maintained a unified control on all pathology research stationwide. However, he no longer reported to a pathologist in Washington, but to the Station Director. With Hepting's assignment to the Washington office staff in 1962, but still headquartered in Asheville, Harry R. Powers, Jr. became the division chief. When the assistant directorships replaced the divisions in 1964, Thomas S. Buchanan returned to the Southeast as Assistant Director for Fire, Insects, and Disease, remaining until his retirement in 1972. This still permitted at least some semblance of unified supervision of disease research. After Buchanan retired, the assistant directors were assigned geographic areas rather than subject matters. Thereafter, effective technical supervision dropped to the project leader level.

Personnel

In 1954, the pathology staff consisted of:

At Asheville:

George H. Hepting, Chief of the Division of Forest Disease Research.

Elmer R. Roth, Hepting's main assistant. In 1958, Roth transferred to State and Private Forestry in Atlanta.

John S. Boyce, Jr., working on needle cast, annosus root rot, and oak wilt. About 1961, Boyce resigned to accept a position at the University of Georgia.

W. A. Stegall, a former blister rust aide, reported in 1954 as a subprofessional and worked in the surveys of oak wilt, sweetgum blight, air pollution damage, and white pine blister rust. He died in 1968.

At Athens-Macon:

William A. Campbell remained as Project Leader and Director's Representative until he retired in 1971.

Bratislav Zak remained until 1962 when he transferred to the Pacific Northwest Forest and Range Experiment Station.

A. Alfred Foster, working out of Lake City, had such spectacular results in nursery disease control, saving two Georgia State Nurseries from abandonment because of root rot, that the Georgia State Forester offered to finance much of Foster's expenses and salary if he were moved to Georgia. As a result, Foster went to Athens for a short time then to Macon, Georgia, where the Georgia Forestry Commission was headquartered and near one of the largest tree nurseries. Foster spent the next few years (1953-1961) making a name for himself by cleaning up nursery disease problems by soil fumigation. Production at the Georgia nurseries was dramatically increased and weeding costs decreased by fumigation. Foster resigned in 1961 to accept a position with the Tennessee Valley Authority.

B. E. Hopper, about 1956, spent a year at Athens studying nematodes in nurseries before joining the faculty at Auburn University.

Many of the early pathologists had left by 1954: R. P. True was professor of forest pathology at the University of West Virginia, E. R. Toole transferred to the Southern Station in 1952; R. B. Clapper retired in 1953, Otis L. Copeland left in 1954; T. S. Buchanan enlisted in the marines in 1945 and after working in industry and Liberia joined the Washington staff before returning to Asheville in 1964 as an assistant director; and L. W. R. Jackson joined the School of Forestry at the University of Georgia in 1946.

Starting in 1955, considerable new young blood was added to the pathology staff:

W. Craig Bryan after completing a major study of defects in Piedmont hardwoods, joined the littleleaf staff at Athens in 1955 and later helped Zak with mycorrhizae research. Currently, he is working on endotrophic mycorrhizae in the Institute of Mycorrhizae at Athens.

Charles R. Berry came to Asheville in 1957 to study air-pollution, but also spent time on rehabilitation of littleleaf sites. Since 1971 he has been in the Institute of Mycorrhizae.

Charles S. Hodges, Jr. started working on nursery diseases under Foster in 1958. After getting his doctorate at the University of Georgia he went to Raleigh, N. C. on Soil Bank funds to help the states of North and South Carolina improve their tree nurseries by increasing production and reducing weeding costs through soil fumigation. Later he was transferred to the Research Triangle Park on annosus root rot. Hodges resigned in 1973 but returned after a foreign assignment and currently is at the Institute of Pacific Islands Forestry in Honolulu.

Frederick R. Matthews, previously a summer assistant on oak wilt in the early 1950's, developed controls for cone rust in seed orchards during 1958 to 1961 at Lake City. He is now at Athens on fusiform rust.

Samuel Rowan reported to Macon in 1958 on nursery diseases. In 1962, he returned to school at the University of Georgia and since 1968 has been at Athens on fusiform rust and root rot in nurseries.

Harry R. Powers, Jr., Hepting's chief assistant in Asheville from 1960 to 1962, became Chief of the Division of Forest Disease Research. After the Assistant Directorships were established, Powers transferred to Athens to develop methods for mass testing of pine seedlings for resistance to fusiform rust. Later, he became Project Leader for Diseases of Plantations and Seed Orchards, which currently includes all disease reseach at the Southeastern Station.

Elmer G. Kuhlman joined the Asheville staff in 1961. He is now at Research Triangle studying annosus root rot, fusiform rust, and more recently pitch canker and chestnut blight.

John L. Ruehle reported to Athens in 1961 and was assigned to the Soil-borne Disease project to study nematodes associated with tree roots. Recently, he has been working on mycorrhizae in the Institute of Mycorrhizae.

Donald H. Marx, while working on his master's degree in 1961, was an assistant to Zak on mycorrhizal studies at Athens. He moved to the Research Triangle in 1963 while completing his doctorate at North Carolina State. He returned to Athens in 1966 as a member of the Soil-borne Organisms project under Campbell. On Campbell's retirement in 1971, Marx became Project Leader until 1976 when the project was reorganized as the Institute of Mycorrhizae with Marx as Director.

Guy V. Gooding, Jr., joined the Research Triangle staff in 1962 to work on serology, viruses, and fusiform rust. In 1965, he joined the faculty of North Carolina State University.

F. F. Hendrix spent 1962 to 1964 in Asheville on annosus root rot. Since then he has been in Plant Pathology at the University of Georgia.

Ronald W. Roncadori was on the rusts, nursery, and hardwood disease project at Macon and Athens from 1963 to 1966, and then went to Plant Pathology at the University of Georgia.

Thomas Miller started in 1964 at Macon and worked on site effects of fusiform rust. Then, after two years at the Research Triangle on his doctoral program, he transferred to Athens were he is currently on seed disease problems under Powers.

Eldon W. Ross spent 1965 to 1971 at Athens on annosus root rot after which he went to Washington as Assistant in the Division of Forest Insect and Disease Research. He was Assistant Director at the Northeastern Forest Experiment Station for Continuing Research Programs in Ohio and Pennsylvania, until returning to Asheville in March 1979 as Station Director.

Jerome W. Koenigs was at the Research Triangle from 1966 to 1977 on basic research on the biochemistry of wood decay and the physiology of decay fungi. He also worked on annosus root rot and other problems. He resigned in 1977, and accepted a position with the International Paper Company.

L. David Dwinell reported to Athens in 1966 and worked on fusiform rust. From 1968 to 1972 he took over responsibility for INTREDIS from Hepting and currently is under Powers on fusiform rust and pitch canker.

Otis C. Maloy, Fields Cobb, Arthur Rhoads, and W. A. Costonis also spent short periods at the Southeastern Station during this period.

Research Problems

Littleleaf, heartrot, black root rot, and some other diseases given concentrated attention in the past remained important factors in forest management but did not require further intensive research. By 1950, a host of new problems appeared that required immediate research effort by pathologists. Oak wilt threatened to devastate the oak forests; sweetgum blight became common throughout the host range; cone rust impeded seed production in seed orchards; white pines were dying from what later was shown to be air-pollution damage; annosus root rot increased in importance as more southern pine plantations reached the thinning stage; and fusiform rust had become a formidable factor.

Some of these, as oak wilt and sweetgum blight, have ceased to be major problems; cone rust and black root rot remain important but are kept in bounds by economical controls; others, as fusiform rust and littleleaf, remain vexing problems requiring intensive research, and some, as pitch canker and annosus root rot, remain important problems locally. Currently, fusiform rust is the major research subject at both the Southern and Southeastern Stations. Originally, research on this rust was assigned to the Southern Station but in the 1960's, forestry interests in the Southeast requested that research be expanded to include the Southeastern Station also and, as a result, the two stations have teamed up for a concerted attack on this No. 1 disease of southern pines.

The pathology satellite centers at Auburn, Union, and Macon were closed by 1953 or soon thereafter. Lake City was inactive after Clapper's retirement in 1953 until Frederick R. Matthews was stationed there (1958-1961) to develop controls for cone rust. Since his transfer to Athens in 1961, no pathologists have been stationed at Lake City. This center, the logical choice for the naval stores studies, is too isolated for most long-time pathology research.

A new satellite was established near Raleigh, N. C., in 1962, in the Research Triangle Park, with a primary function to study soil-borne organisms. Prior to 1962, pathologists on this project had been temporarily located at Chapel Hill and Raleigh, N.C. The Research Triangle was intended to be the main research center for forest disease research in the Southeast, but circumstances dictated that the Athens Center assume this responsibility. In 1963, the main soil-borne organisms project was transferred to Athens and the

Research Triangle concentrated on annosus root rot, although other studies included pitch canker, basic research on wood decay, and recently, chestnut blight. The pathology staff at the Research Triangle was reduced to one pathologist in 1977 under the supervision of Powers at Athens. Thus, forest disease research currently is concentrated at the Athens Research Center.

Research Results

Research findings during the early and CCC periods already have been considered under those sections. Also, no attempt is made to include all findings of the many minor researches or any findings after 1975. Thus, the evaluation of such studies as the recent ones on the effect of mycorrhizal fungi on growth of plantation trees is left to future historians. The most significant reports during the first 40 years of pathology research, as seen by George Hepting, are included in the following lists he gave me. These lists are, with some editing:

The Most Exciting Research Results

1. Putting together the jigsaw of hundreds of matings that established the sex and compatability makeup of the oak-wilt pathogen.

2. Proving that actidione and phytoactin are ineffective in blister rust control and convincing the Forest Service and wide commercial and governmental interests of this.

3. Proving that most butt rot in sprout oaks comes from the parent stump, not from dying appended sprouts.

4. Showing a clear association between stack gas from soft-coal-fired power plants and the killing of pines in Tennessee and Pennsylvania.

5. On a first long-chance gambit, discovering and propagating wilt-resistant mimosa trees.

6. Finding the cause of failure in wood training aircraft (WW-II), that grounded all PT-19's and PT-10's until the cockpit wash-water practice was stopped.

7. Developing fumigation of nursery beds, saving southern nurseries and revitilizing southern nursery practices.

8. Perfecting the first electronic literature storage and retrieval system in forestry.

The Most Valuable Research Results

1. Showing the relation of butt rot to wound age and size in oaks.

2. First enunciating the theory of compartmentalization of heart rot in trees in 1935.

3. Relating changes in climate to oak decline, sweetgum blight, pole blight, maple decline, ash dieback, *et al*.

4. Establishing the techniques used in the current testing of southern pine seedlings for resistance to fusiform rust.

5. Proving that ozone, in addition to soft coal stack gases, is a major air pollutant affecting conifers.

6. Producing the compendium on American tree diseases.

7. Discovering the causes of, and naming the pathogens of several new diseases: pitch canker, two hemlock blights, stem rust of Virginia pine, mimosa wilt, sumac wilt, and nectria canker of yellow-poplar.

Cankers

Nectria and *Strumella*, the most important canker fungi on Southern Appalachian hardwoods, were important factors in the CCC timber improvement operations, even though little was known about handling them. Among the researches started in the CCC period was a longtime field study on the effects of eradicating cankered trees on subsequent cankering. Eighteen years' observations showed that eradication was unnecessary with *Nectria* and ineffective against *Strumella* (Roth and Hepting 1954). They concluded that the best handling consisted of selecting canker-free trees for crops trees and utilizing cankered trees in thinning operations.

Pine Pitch Canker. In 1946, Hepting and Roth reported a new canker on Virginia pine, in which the causal fungus rapidly kills or seriously deforms leaders, branches, and sometimes the main stem. The causal *Fusarium* later was named *F*. *lateritium* *f*. *pini* (Snyder *et* *al*. 1949). Innoculations proved the susceptibility of all major southern pines except loblolly (Hepting and Roth 1953). South Florida slash pine also has been seriously affected (Bethune and Hepting 1963).

Chestnut blight never was a high priority on the research program at the Southeastern Station. As already mentioned, Humphrey and Nelson did some work on the rate of deterioration and tannin content of blight-killed chestnuts. Also Nelson and Diller planted several thousand exotic and hybrid chestnuts, and later, under Hepting the best six lines of our many Chinese chestnut imports were planted under more controlled conditions. In recent years, a search was being made for living American chestnuts that might be resistant. When Clapper joined the Lake City staff in 1948, he continued his interest in possible resistance in American and Asiatic chestnuts and various hybrids. He had been active in the field for almost 25 years, working with R. Kent Beattie and Diller. Nothing very promising in terms of forest trees came of this research (Diller and Clapper 1965).

During World War II, the Southeastern Station pathologists submitted a detailed investigative report, requested by The War Production Board, on the amount of chestnut wood available for tanning leather, and how long the supply would last. The rate of deterioration of blight killed chestnut was redetermined. Rot progressed at the rate of 1.5% per year while loss of tannin content was 3.5% per year but more as decay increased (1951. Southeastern Sta. Ann. Report).

Kuhlman recently has reactivated chestnut-blight work at the Research Triangle, checking on European claims of natural abatement of the blight there through changes in the causal fungus.

Heartrots

As already pointed out, heartrot was a major field of investigation at the Southeastern Station during the early and CCC periods. However, several important studies were reported during the 1940's and 1950's:

1. Decay, discoloration, and cankering follow increment boring of hardwoods and to a much less extent pines (Hepting *et al*., 1949).

2. Fruiting of decay fungi on felled trees (Hepting and Roth 1950). Some fruiting, particularly *Fomes*, occurs up to 5 years after felling but, never-the-less, felling conky trees is a good sanitation measure.

3. Decay following thinning of sprout oak clumps (Roth 1956), as influenced by sprout diameter and crotch type.

4. Healing and defects following oak pruning (Roth 1948) as influenced by season and wound width. Earlier, Roth and Hepting (1943b) reported on the rate of healing when large companion sprouts are removed and on the chances of decay in the remaining sprout.

5. Origin and development of oak stump sprouts as affecting their decay hazard (Roth and Hepting 1943).

6. Developing a formula to correlate the rate of butt rot development in oak with the age and size of fire wounds (Hepting 1941). This publication is one of the most significant heartrot reports.

7. A number of taxonomic reports of decay fungi by Campbell with Davidson and others.

Littleleaf Disease of Shortleaf Pine

In 1940, after Siggers (see Southern Station Pine Disease Project) made the original survey, described the disease, named it littleleaf, and recognized it as a root disturbance, research on littleleaf was assigned to the Southeastern Station. Hepting initiated a major, multifaceted research attack on this serious and complex disease. During the 1940's and early 1950's, most of the pathologists at the Southeastern Station did at least some work on littleleaf but only the key people will be mentioned here. Hepting directed the program and worked on the management of littleleaf stands and on the nutritional phases; Campbell concentrated on the fungus features; Copeland studied the relationship of soils to the disease; Zak, and later Bryan, studied the possibility of resistance to littleleaf in shortleaf pine. These researches, based on surveys, permanent plots, and laboratory and greenhouse studies, resulted in a wealth of basic and practical information reported in many publications. In the nutritional studies (Roth, Toole, and Hepting 1948), nitrogen was the only soil amendment that helped relieve symptoms and was the only element found to be largely deficient in littleleaf trees.

Campbell and Copeland (1954) summarized the knowledge of littleaf disease in USDA Circular 940. In essence, the symptoms of littleaf are an expression of nitrogen starvation as a result of the death of feeder roots by attacks of Phytophthora cinnamomi, favored by heavy, poor soils with low internal drainage and aeration. Also included in the circular are discussions of symptoms, distribution, the handling of diseased stands, breeding for resistance, and soil rehabilitation.

About 1950, George A. Zentmyer, on sabbatical from the University of California, helped Campbell in identifying Phytophthora species associated with littleleaf disease and forest soils.

The management of littleleaf stands (Campbell, Copeland, and Hepting 1953) includes predicting hazard by soil series and condition, and proposes that cutting cycles be based on severity of attack if a maximum of wood is to be salvaged. Long-time solution may be soil rehabilitation by favoring soil building hardwoods to create more favorable soil organic content and micro-flora populations (Hepting and Jemison 1950) and possibly the development of resistant strains of shortleaf pine (Bryan 1965).

Wilts

Oak wilt. In the early 1950's oak wilt attracted considerable attention, leading to research programs by several States, notably Arkansas, West Virginia, Missouri, and Wisconsin. In the South and Southeast, Federal research was concentrated at the Southeastern Station. They conducted the early surveys from Virginia to Arkansas in 1951 and 1952. Later the States assumed responsibility for surveys and control programs. Most of the Southeastern Station's survey from 1953 to 1957 primarily were to check the effectiveness of control programs and to determine spread in specific areas.

Research, including that based on surveys, included:

1. Sexuality of the causal organism (Hepting, Toole, and Boyce 1952; Boyce and Garren 1953), including information on the distribution of sexual forms A and B within trees and infection centers. These findings partially explain slow overland spread and were valuable in interpreting field results.

2. Felling diseased trees, spraying the logs and large branches with a mixture of pentachlorophenol and BHC in fuel oil and treating the stumps with ammate greatly reduced insect dissemination (Boyce 1959).

3. Summer-felled trees form no fruiting mats the following spring when most insect activity occurs (Boyce 1954).

4. Longevity of the fungus in oak lumber cut from diseased trees (Englerth, _et al_. 1956). Steaming, kiln drying, and air seasoning to 20 percent moisture or less killed the fungus, but it can live for several months in logs and lumber before the wood is dried or otherwise treated.

5. Hepting summarized research on and the status of oak wilt in the United States (Hepting 1955).

During the past two decades, oak wilt has subsided, followed by corresponding reduction in research effort. However, mysteries remain. Is the pathogen a widely distributed, native organism, with a weak means of dissemination that flared up because of an unknown temporary environmental factor? This gains some credence by the fact that oak wilt appeared first, and was most severe in the transition zone from forest to prairie where it previously had been without causing appreciable damage. Whatever the answer, the oak-wilt fungus can be highly virulent, and given a more efficient disseminating agent and favorable environmental conditions, could devastate our oak forests.

Mimosa wilt first described by Hepting in 1936, soon threatened to and almost did wipe out mimosa in much of the Southeast and South. Research by Toole, Hepting, and Snyder included the taxonomy of the causal *Fusarium* (Snyder *et al*. 1949), the life history of the pathogen, variability in culture and in virulence, pathogenicity in various tree species (Toole 1941), and the development of resistant strains of mimosa (Toole and Hepting 1949). The development of virtually immune clones of mimosa is important because it is the first demonstrated instance of very high resistance to a fungus pathogen within a tree species. The resistant strains have stood up remarkably well in widespread ornamental use for 30 years.

Staghorn Sumac Wilt. The causal Fusarium was found in 1948, and named as a new form of Fusarium oxysporium f. rhois (Snyder et al. 1949). The history, symptoms, and etiology of this wilt was summarized by Toole (1949).

Nursery Diseases

When Foster reported for nursery disease work, pine nurseries in Georgia were in such a precarious condition that abandonment of some was being considered. Black root rot was the main culprit. Foster established some practical soil fumigation trials and later studied such practices as irrigation, fertilization, and seed bed density as affecting disease and yield. Being essentially an extension pathologist, Foster implemented his findings and soon the Georgia nurseries were in a healthy, viable condition. The published reports of Foster's findings are meager in comparison to their importance. However, he did report: (1) Soil fumigation to control black root rot (Foster 1961); (2) Reducing the number of ferbam sprays to control fusiform rust by timing sprays with weather suitable for infection (Foster and Krueger 1961); and (3) Fungicidal spray control of Phomopsis blight of Arizona cypress (Foster and Harrison 1957). Foster also prepared the original version of Forest Pest Leaflet No. 32 on nursery disease of southern pines.

Hodges, who started his nursery studies under Foster, solved many disease problems in nurseries in North and South Carolina much as Foster had done in Georgia. Later he reported on a number of research findings: (1) The effect of nursery infection with *Phomopsis juniperovora* on the survival of junipers on outplanting (Hodges and Green 1961); (2) Subjecting pine seedlings to prolonged periods of subfreezing temperatures during transit and storage, greatly reduces survival on outplanting (Hodges 1961); (3) Fungi isolated from nursery soils over a 5-year period (Hodges 1962); and (4) Proof that *Sclerotium bataticola* and *Fusarium oxysporum* cause black root rot (Hodges 1962). Hodges also published several purely mycological papers.

Nematodes

At both the Southern and Southeastern Stations, pathologists studying nursery diseases knew that nematodes commonly were associated with tree seedlings. A survey of nurseries in 1956 and 1957 showed that a number of genera of nematodes were potentially parasitic on pine roots, but obvious damage was associated only with *Meloidodera* and *Tylenchorhynchus* (Hopper 1958). Hodges (1958) reported that soil fumigation eliminates parasitic nematodes for a year while non-parasitic ones repopulate the soil rapidly. At Lake City pine seedlings were found to be undamaged by a hot water treatment that kills cyst nematodes.

However, it wasn't until John L. Ruehle, nematologist, joined the pathology group at Athens in 1961, that the real role of nematodes began to emerge. From surveys of nurseries, plantations, and natural stands, made from 1961 to 1963, and from the literature, Ruehle cataloged the nematodes associated with southern pines and with other conifers and southern hardwoods. Greenhouse tests showed that some nematodes can damage seedlings: (1) Several genera on southern pines; (2) A sting nematode on sycamore; and (3) A dagger nematode on sweetgum. This work was summarized by Ruehle (1973).

Ruehle and Marx found that a lance nematode parasitizes the ectomycorrhizae of pines. In relationship to littleleaf disease, Burham, Marx, and Ruehle (1974) showed that nematodes, by breaking the fungal mantle, create points of entry for _Phytophthora cinnamomi_. Ruehle has summarized the information on the association of nematodes and forest trees (Ruehle 1973). He concludes that nematodes can interfere with normal mycorrhizal formation by damaging the root cortex, by suppressing the mycorrhizal fungus, and that parasitic nematodes may directly or indirectly cause pathological symptoms commonly attributed to such factors as poor soil, drought, soil erosion, and compaction.

Mycorrhizae

Mycorrhizal studies started in the late 1940's when Jackson (1947) devised a differential stain for mycorrhizal roots, but it wasn't until the 1960's that intensive mycorrhizal research started in the Southeast. A number of mycorrhizal fungi were isolated from southern pines, and Bryan and Zak (1961) synthesized mycorrhizae in culture flasks. Methods were developed to isolate mycorrhizal fungi from roots (Zak and Bryan, 1963; Zak and Marx 1964). Marx, Zak, Bryan, and Davey (the latter of the University of Georgia) determined the effect of pH (Marx and Zak 1965) and of temperature (Marx *et al*. 1970) on mycorrhizal formation.

Marx and Bryan (1969) devised a growth chamber in the greenhouse where air-filtering, fumigating, and air-conditioning made it possible to study mycorrhizal phenomenon under more controlled conditions. The same year, Marx and Davey published in volume 59 of Phytopathology a series of papers on the influence of ectotrophic mycorrhizae on the resistance of pine roots to infection by pathogenic fungi. One fungal symbiont produced an antibiotic which at 2 ppm totally inhibited the littleleaf fungus and at higher concentrations was lethal. In a second paper he showed that several mycorrhizal symbionts in agar plates inhibited the growth of about half of 48 root pathogens tested. In the third and fourth papers

Marx and Davey showed that roots with mature mycorrhizae are resistant to *Phytophthora* but those with incipient mantles become infected. Since *P. cinnamomi* is a common soil fungus, and all mycorrhizae start with incipient mantles, the effect of mycorrhizal fungi on infection seems minimal. Later, Ross and Marx (1972) reported that mycorrhizal roots of sand pine also are resistant to *P. cinnamomi*. As already mentioned, Ruehle and Marx reported that lance nematodes parasitize mycorrhizal mantles and permit infection by the littleleaf fungus.

Most of the mycorrhizal studies at Athens were under the Soil-borne Organisms project, but recently the mycorrhizal phases have been separated in the Institute of Mycorrhizae, a Research and Development project with country-wide studies aimed at improving planting survival and growth by ensuring that seedlings have a suitable mycorrhizal fungus present when planted. Marx is Director.

Sweetgum Blight

The Southeastern Station, in 1954, sponsored, with the cooperation of Southern and Northeastern Stations, a survey of sweetgum stands from Maryland to Louisiana (Hepting 1955a). Severe dieback commonly was found throughout the range of sweetgum. Studies by F. H. Berry (Bureau of Plant Industry) had eliminated fungi, viruses, nematodes, and nutrients as the probable cause. Toole and Broadfoot (see Southern Station hardwood project) showed that blight was a response to moisture shortages, particularly on certain soil types. Decline stopped with the return of normal rainfall, and what threatened to be a major problem in 1954, essentially disappeared a few years later.

Air-Pollution Damage

A new disease of eastern white pine--characterized by browning of new needles from the tips, reduced growth, and sometimes death--began to cause concern in the Southeast about 1945 (Toole 1949a). Later it was found that at least two troubles were involved (Hepting and Berry 1961). Emergence Tip Burn, resulted from ozone damage during periods of high atmospheric oxident content (Berry and Ripperton 1963) and Post-Emergence Chronic Tipburn (PECT). PECT is due to air-pollution. In cooperation with TVA, University of Tennessee, and the Tennessee Division of Forestry, a study was undertaken in 1957 to ascertain the cause of PECT. Pruning, fertilization, transplanting, isolating from roots and stems, foliage analysis, and grafting, eliminated adverse soil conditions, severe climate, or pathogenic organisms as the cause and pointed to stack gasses from TVA's Kingston coalburning power station as the probable cause (Berry and Hepting 1964). Recent observations in the worst damage areas show that most susceptible white pines have been eliminated, but many individuals remain that resist PECT, and these have been reproduced by grafting to comprise a seed orchard. Hepting has summarized the impact of air-pollution on trees (Hepting 1971b).

Products Pathology

Although fungus deterioration of forest products was never a major field at the Southeastern Station, some noteworthy results have come from there. Already mentioned is Roth's report that invisible incipient decay increases the decay rate of oak ties and posts even though the decay in service is by different fungi than those present in the incipient decay (Roth 1943).

Hepting (1945) studied decay and stain in stored peeled and rough southern pine pulpwood as influenced by different storage methods.

Wood planes were the mainstay of the Army Air Corps Pilot Training Program in WW-II. Moisture problems at one time grounded many planes. Hepting (1944) determined that washwater in cockpits was the main source of water leading to decay, but rain and splash from wet runways also were factors. Revised washing procedures corrected the main fault. Keeping grommets open helped drainage, and the use of marine-type grommets reduced the entry of splash water.

Yellow-poplar aircraft veneer was in short supply because grading rules eliminated discolored wood. Hepting, Roth, and Luxford (Forest Products Laboratory) (1942) determined the effect of discolorations on strength and the results increased acceptable wood by 25 percent. Red, yellow, lavender, purple, grey, and green discolorations did not reduce strength; brown and black discolorations or roughened surfaces indicated decay and reduced strength.

After World War II, the Navy stored many wooden boats for possible future use. Decay soon became a problem. Carl Hartley (Beltsville) headed a project to determine if the deterioration could be reduced. Elmer Roth, under Hartley's direction, made observations and conducted tests on stored boats along the South Atlantic coast. Roth and Hartley (1957) reported to the Navy that dynamic dehumidification of hulls protected most interior members above the water line and that fungicides in the bilge water helped protect below water parts but only a rain shelter over the boats would protect exteriors.

Although not engaged in building decay research, the Housing Project (Forest Utilization Service) at Athens reported on studies of moisture conditions within frame walls under more controlled conditions than had been possible in the Southern Station's building decay studies.

Naval Stores

Fungus Stimulation of Gum Flow. Soon after pitch canker was found in 1945, Hepting recognized that the then unidentified *Fusarium* causing the canker, might have value in the naval stores industry. So in June 1945, he inoculated some turpentine wounds with *Fusarium* and found increased gum flow on longleaf, Virginia, and shortleaf pines (Hepting 1947). He took out a public patent on the fungus stimulation of gum flow to prevent private exploitation. Further inoculations made at Lake City by True and Snow, as already discussed in research at the Southern Station, showed similar stimulation of gum flow, particularly on slash pine. After True left in 1949, R. B. Clapper continued the studies. He summarized the researches (Clapper 1954): (1) For a short period Fusarium-inoculated trees yielded more resin than acid-treated faces, but, over a period of a year, the two yielded about the same amount. (2) Among various isolates tested, two mutants stimulated more than the parent isolates and metabolic products of the *Fusarium* caused insignificant stimulation. (3) Pitch soaking of wood back of inoculated faces might be developed to practical use for solvent extraction. He also included a review of previous research.

Dry Face. *Diplodia pinea*, *Gloeotulasnella pinicola*, and *Ceratostomella ips* can cause "dry face" although drought and other non-pathogenic factors are the prime causative agents (True 1947).

Pitch Streak. Stain, pitch soak, dry wood, and rot commonly occur as streaks extending well above turpentine faces, particularly when dry face occurs (True and McCulley 1945). Cobb (1957) found that pitch streak occurs mainly in trees of low vigor on droughty sites, particularly when faces are wood chipped. It is primarily a physiologic disorder and was epidemic during the dry years of the mid-1930's and mid-1950's.

Fomes annosus

Annosus root rot was found in several thinned white pine plantations in North Carolina (Hepting and Downs 1944, Boyce 1962). Sporulation was reported every month of the year. Other reports and surveys included *F. annosus* on *Pinus rigida* (Roth 1952) and on redcedar, particularly on eroded soils where the fungus was fruiting on pine stumps (Dwyer 1951). By 1960, when extensive pulpwood plantings of slash pine had reached the thinning stage, F. annosus damage reports began coming from many locations, and it was obvious that annosus root rot would be an important factor in the management of southern pine plantations. To prepare for a comprehensive research program, a southwide survey of southern pine stands was made in 1960-61 with the cooperation of the Southern Station. This survey (Powers and Verrall 1962) furnished much of the practical information available on annosus root rot of southern pines. Root rot was more severe in thinned stands on old field sites with coarse-textured soils, deep A horizons, deep litter, and on slopes. At the same time, a research program on F. annosus was initiated which extended into the 1970's. Findings included:

1. Kuhlman and Hendrix (1962) devised a selective medium for isolating F. annosus.

2. Studies of the factors affecting colonization of stumps and the development of Fomes annosus in stumps and roots were conducted by Kuhlman, Hendrix, Hodges, and Ross. Inoculation with spores was more successful than with mycelial fragments. Loblolly pine stumps were susceptible to infection for 12 days in February. Thereafter, Peniophora gigantea increased so rapidly that F. annosus was

suppressed. *P. gigantea* was very active in replacing *F. annosus* in naturally infected stumps and roots. Other fungi, including *Trichoderma viride*, and bacteria apparently have no limiting effect on *F. annosus*. Ross (1973) summarized the information on the relationship of environmental and biotic factors to stump colonization and losses in residual stands.

3. Some stump treatments with creosote and ammonium fluoride were established in 1962 and later with borax (Hodges 1970). Only borax significantly reduced infection. In laboratory tests, borax had very low toxicity to *F. annosus*. Therefore, some mechanism other than toxicity must explain the effectiveness of borax on stumps (Koenigs 1969).

4. *F. annosus* can attack and kill 3-year-old slash pine seedlings (Ross and Hodges 1964).

5. Some differences in susceptibility among southern pine species occurs, but the differences are not considered of practical significance (Hodges 1969; Kuhlman 1970).

6. Kuhlman reported on: (a) greenhouse inoculations (1969), (b) the number of spores needed for stump infection (1969), (c) survival of spores in soils (1969a), (d) artificial

inoculations, in which some variation in virulence and host susceptibility was found among isolates from several countries (1970), and (e) successful regeneration of pines on annosus-infested sites (Kuhlman and Ross 1970). In contrast to "d" above, Koenigs (1970) reported no practical differences in infectivity among isolates from six countries.

Even though _F_. _annosus_ commonly fruits on stumps on low- and high-hazard sites, infection and death of residuals is significantly greater on high-hazard sites (Kuhlman 1973).

7. In laboratory tests with pine bolts, _F_. _annosus_ was suppressed at 35°C and killed at 40°C, indicating that high temperatures may play a role in survival in stumps (Gooding 1964). In wood chips, _F_. _annosus_ was killed at 40°C in 2 hours. Because stump surfaces reach 40°C or higher for periods of at least 2 hours on more than 50 percent of the days in May through August in the Southern pine belt, temperature can limit stump infection during summer (Gooding _et al_. 1966). Later, Ross (1969), after further laboratory trials, suggested that neither conidia nor basidiospores are expected to survive on stump surfaces more than 1 hour at 45°C and 95 percent relative humidity. These studies have led to practical suggestions that summer thinning on high-hazard sites will reduce root rot losses.

8. Hendrix and Kuhlman (1964) reported some direct root infections on slash pine but infections through adjacent stumps are more common.

9. Hodges (1969a) summarized the information on infection and spread of _F. annosus_. The Southeastern and Southern Stations translated the latest research information into practical guides to minimize losses from _F. annosus_ (Kuhlman _et al_. 1976 and Froelich _et al_. 1977). These publications describe the determination of site hazard and the use of borax stump treatment, summer thinning, prescribed burning, species substitution, etc., in order to reduce losses.

Rusts

White Pine Blister Rust was first reported in North Carolina in 1945. Yost (Plant Disease Control, BPI) and Hepting cooperated in laying out plots to study rust spread. In the 1950's, pathologists of the Southeastern Station made a survey to assess damage and assisted the State of North Carolina and the North Carolina National Forests with Ribes surveys to establish hazard areas and advise on methods of Ribes eradication. Many areas harboring white pine and Ribes were shown to pose no blister rust hazard because of high summer temperatures, and thus Ribes eradication was not needed.

The Southeastern Station's important contribution on white pine blister rust came later when they proved that the cycloheximide systemics were ineffective in controlling blister rust (Powers and Stegall 1965). After some discussion, this finding was accepted and actidione and phytoactin were removed from control programs; but not before millions of dollars had been spent on their use.

Cone rust, although known for many years, did not assume importance until research on southern pine breeding was started, and when seed orchards became a reality. Then, periodic heavy losses from rust demanded control. The Southern Station attacked it from the research geneticist's point of view, i.e. bagging flowers; the Southeastern Station attacked it in terms of seed orchard protection, i.e., fungicidal control. At the start, fungicidal protection seemed a ticklish operation because rust spores and pollen coexisted on receptive pistillate flowers, requiring a selective fungicide lethal to the spores but harmless to the pine flowers and pollen. Spray trials, started in 1957, showed that ferbam prevented rust infection and not only did not harm pine flowers but actually stimulated pollen germination (Matthews and McLintock 1958). Matthews (1964) summarized the information on cone rust, including research results on daily sporidial counts, the effect of weather on sporidial production, fungicidal spray schedules, and the effect of fungicides on seed set and seed germination.

Fusiform rust. Even though the Southeastern Station did not engage in major research on fusiform rust until the mid-1960's, they earlier discovered that: (1) Aeciospores will not infect pines (1949-50, SE Annu. Rep.); (2) Fusiform rust can be an important obstacle to establishing grafted seed orchards (Campbell *et al.*, 1962); (3) Actidione is ineffective against fusiform rust (1961, SE Annu. Rep.); and (4) Fungicides can control the rust in nurseries (see Nursery-Disease section). Since 1965, fusiform rust has been the subject of major disease research. Serological tests showed that *C. fusiform* and *C. quercuum* differ in at least one antigen (Gooding and Powers 1965), but separation on the basis of gall shape is uncertain (Powers 1971). Dwinell (1971) showed that black oak seedlings of known resistance to *C. fusiforme*, can be used to separate the two species. Powers (1969) inoculated 16 pine species with *C. fusiforme* and *C. quercuum* and found Jeffrey, Monterey, and ponderosa pines were susceptible to fusiform rust. Since these pines and the California black oak are susceptible, fusiform rust could be a threat to western pine forests (Dwinell and Powers 1974). Later tests established more fully, the relative susceptibility of six pines native to the Carolinas (Power 1975).

Dwinell rated the susceptibility of 24 species of southern oaks to _C_. _fusiforme_ and _C_. _quercuum_ based on the number of telia produced following aeciospore inoculation (Dwinell 1974). Water and willow oaks were highly susceptible to _C_. _fusiforme_ and 10 species reacted significantly differently to the two rust forms.

Many studies on spores were conducted: (1) Abjection of secondary sporidia (T. Miller and Roncadori 1966); (2) The effect of telial column age on germination and sporidial production (Powers and Roncadori 1966); (3) Storage and germination of aeciospores (Roncadori and Matthews 1966); (4) Secondary and tertiary sporidia can infect pine (Roncadori 1968); (5) Sporidia can remain viable up to 8 weeks at 5°C (T. Miller 1970).

Other Research included:

1. Powers and coworkers also reported on volume loss from fusiform rust in young slash pine plantations (Powers _et_ _al_. 1974).

2. T. Miller (1972) confirmed Siggers' report that intensive site preparation increases rust hazard. Site class, however, had no effect.

3. Powers (1968) found that the distance of cotyledon infection from the stem determined if infection will reach the stem because, if too far out, normal cotyledon death occurs before the rust reaches the stem.

4. Koenigs (1968) reported that under some conditions, telial germination and sporidial discharge can occur faster than previously reported. This finding, plus the rapidity of seedling growth exposing untreated tissue, may explain occasional fungicidal failures.

Southeastern Station's Research and Development Program perfected a technique for large-scale testing to determine resistance of southern pine selections to fusiform rust (Matthews and Rowan 1972, Powers 1974). The R&D personnel prepared a detailed manual covering all phases of the test procedure. The testing program, available to State and industry, as well as Federal Agencies, is being operated at Bent Creek, N.C., by the USDA Forest Service's State and Private Forestry.

Recently, most research effort is on the selection of southern pines resistant to fusiform rust and their establishment in seed orchards. A relatively recent finding affecting such a program was the discovery of physiologic races of *C. fusiforme* differing in pathogenicity. Much of this work is being done jointly with the Southern Station.

Miscellaneous Rusts. The hemlock twig blight, caused by *Melampsora farlowii*, caused heavy losses in nurseries in the mid-1930's. Hepting and Toole (1939) describe symptoms and defined the range, importance, etiology, epidemiology, and fungicidal control. The control measures are now in general use. *Cronartium appalachianum* on Virginia pine was described as a new species, with *Buckleya distichophylla* as the alternate host (Hepting 1957). In 1967, Powers reported that *Cronartium comandrae* was causing important damage to loblolly pine in eastern Tennessee. Later work evaluates resistance of various southern pines and recommends species for use on high hazard sites (Powers 1972).

Miscellaneous Diseases

Needle Blight. Boyce wrote his doctoral thesis on *Lophodermium pinastri*, finding that it was essentially nonpathogenic on southern pines. He continued his interest in needle blights at Asheville, proving that the brown-spot fungus was responsible for needle blights of loblolly and eastern white pines and that *Hypoderma* lethale caused a similar blight of at least six species of southern pines. Boyce (1958) summarized and gave references to these researches in Forest Pest Leaflet 28.

Defects in Piedmont Hardwoods. W. C. Bryan (1960) extensively studied defects in Piedmont hardwoods from 1955 through 1958 by external examination of many trees and 16 mill-scale studies. The factor most influencing defects was small size of trees, particularly as influencing epicormic and adventitious branching, small knots, and stem distortions. Cankers, rot, bird peck, and insect damage were less important than tree size.

Roth (1950) studied the possible causes of discolorations in living yellow-poplar trees, finding that bacteria, commonly present in discolored heartwood, were not responsible. Discoloration follows wounding, broken branches and tops, fire scars, insect injury, and logging damage. The common stains in yellow-poplar apparently are mineral stains resulting from oxidation phenolic reactions.

Spot Die-Out of Loblolly Pine. Planted stands of loblolly pine, particularly on heavy Piedmont soils, after normal growth, suddenly fade and die. Copeland and McAlpine (1962) ascribe die-out to localized unfavorable soil, i.e. poor aeration and permeability leading to root mortality. Thus, it resembles littleleaf, but apparently without pathogenic involvement.

Sapstreak of maple, which caused epidemic dying of residual maples following logging, was first observed about 1940 on the Pisgah National Forest (Hepting 1944) and later in a number of localities in the Lake States. The causal fungus, *Endoconidiophora virescens*, is identical to or closely related to the common sapstain fungus on southern hardwood lumber. Roth (1951) found lumber from diseased maples dipped in a sapstain-control fungicide and air seasoned, can be shipped safely to other maple-producing areas.

Literature Storage and Retrieval

Prior to 1940, the number of forest pathologists was small and the literature in the field correspondingly meager. Most pathologists were familiar with the entire domestic and foreign literature on forest pathology. Presently the literature has become so voluminous that a pathologist can keep abreast of only a small specialized segment of it. George Hepting recognized this problem and, in the early 1960's, developed the Internatinal Tree Disease Register (INTREDIS) system of electronic storage and retrieval of the world literature on forest pathology (Hepting 1967). With the help of several pathologists, particularly V. J. Nordin of Canada, the literature abstracted in the Review of Applied Mycology, Forestry Abstracts, Biological Abstracts, and Abstracts of the Air Pollution Control Association was coded, put on cards, and transferred to tape. The code included subject, host, country, pathogen, and abstracting journal. The tapes were stored at Asheville under Hepting's supervision until 1968 when L. D. Dwinell assumed responsibility. In 1972, the storage tapes and responsibility were transferred to the National Agriculture Library in Washington to amalgamate INTREDIS with several other related literature retrieval banks.

UNIVERSITIES

Forest disease research in the South and Southeast was dominated by the U.S. Department of Agriculture (BPISAE and later FS), until the universities began adding forest pathologists to their faculties, either in their departments of plant pathology or forestry schools. Many of these pathologists (including Boyce, Jewell, Van Arsdel, Toole, and Verrall) came after long service with the USDA Forest Service. Since 1960, the universities of the South and Southeast have assumed an important role in forest disease research, including a significant amount of research in cooperation with the USDA Forest Service.

Some universities, however, had forest pathologists prior to 1960. Also, some earlier research on forest tree diseases and fungus deterioration of forest products was conducted by general plant pathologists at the universities. Already mentioned in the Southern Station section are reports by Edgerton and Hollis *et al*. (LSU) and by Miles (Auburn). However, for this history, emphasis is placed on research by those pathologists spending a major portion of their research effort on forest pathology. Schools without forest pathologists occasionally publish on a forest tree disease but no attempt was made to locate and include all such material.

Much of the information in this section was furnished by the universities. Some schools, however, did not furnish the needed information and, in these cases, I depended on my personal knowledge and on published reports in the Plant Disease Reporter, Journal of Forestry, Forest Science, and Phytopathology plus papers reviewed in the Review of Applied Mycology.

University of Arkansas, Fayetteville, Ark.

Forest pathology research at the University of Arkansas started in the late 1950's when Charles L. Wilson (Ph. D., West Virginia) joined the faculty of the Department of Plant Pathology.

Wilson's researches included: (1) Chlorosis of loblolly and shortleaf pine seedlings associated with high pH and large amounts of K_2O and Ca (Wilson 1959); (2) Oak wilt: survival in material buried in forest litter (Gilespie and Wilson 1960), the growth of Ceratocystis fagacearum in oak wood as indicated by the use of radioactive S_{35} (Wilson 1961), and the nuclear behavior of C. fagacearum (Aist and Wilson 1967, 1968); (3) Blights of Arizona cypress caused by Cercospora thujina (Wilson 1961a) and Phomopsis juniperovora (McDaniel and Wilson 1962); (4) Persimmon wilt including growth of the pathogen within the xylem (Wilson 1963) and a proposal for the use of persimmon wilt as a silvicide for weed persimmon on range land (Wislon 1965); (5) Growth of *Ceratocytis ulmi* in elm wood and the response of the host (Wilson 1965a); (6) The nuclear behavior of fungi: The unique asexual division in *C. fagacearum*, *Fomes annosus*, and some other fungi and the close association of the centriole with nuclear migration (Aist and Wilson 1967; Griffin and Wilson 1967; Armentrout *et al*. 1968).

About 1970, Wilson left Arkansas to become Research Leader, Shade Tree and Ornamental Plant Laboratory (Agric. Res. Serv.) at Delaware, Ohio. He was replaced by Frank H. Tainter (Ph. D. Minn.), Associate Professor.

Tainter has worked mainly on: *Oak wilt*: (1) Survey showing that wilt remains static in Arkansas (Tainter *et al*. 1973); (2) Studies showing that the oak-wilt fungus can be used safely to kill unwanted red oaks (Tainter 1972); (3) Isolations from many inoculated oaks showed that survival of *C. fagacearum* was markedly lower after 8 months, possibly because of high summer temperatures, dying of branches, and sapwood invasion by *Hypoxylon* (Tainter and Gubler 1973). Further studies suggested that *Hypoxylon* rapidly reduces carbohydrate reserves and thus starves *C. fagacearum* preventing it from fruiting (Tainter and Gubler 1974).

Tainter also worked on Comandra rust: (1) A survey established the range in Arkansas (Tainter 1971); (2) The development of the rust in *Comandra* (Tainter 1973); (3) The germination of aeciospores: temperature and pH optima (Eppstein and Tainter 1976) and the presence of a germination self-inhibitor (Eppstein and Tainter 1976a).

The comandra rust studies are continuing, including work on phenology, host range, cytology in pine, and possible development of resistant pine strains. Tainter also has or is doing some work on mycorrhizae, the effect of bromine emmissions from industry on pine, fungi isolated from discolored asphalt shingles, and the dynamics of microbial populations in pine nurseries.

Auburn University, Auburn, Ala.
(Formerly Alabama Polytechnic Institute)

L. E. Miles, Professor of Plant Pathology from 1922 to 1927, collaborated with C. J. Humphrey (U.S. Bureau of Plant Industry) in one of the earliest reports of *Poria incrassata* attack in buildings and stored lumber (Humphrey and Miles 1925).

Forest pathology research at Auburn has been conducted separately and jointly in the Department of Botany and Microbiology and in the Forestry Department. The following have been involved:

Terry C. Davis, Jr. (Ph. D. WVA), Assistant Professor of Forestry and Forest Pathology, 1965 to present.

Walter D. Kelley (Ph. D., North Carolina State), Assistant Professor of Forest Pathology, 1966 to present.

Elroy A. Curl (Ph. D. Ill.), Professor of Plant Pathology, 1954 to present.

James F. Goggans (Ph. D. NC State), Professor of Forestry, 1947 to present.

Jack T. May (Ph. D. Michigan State), Associate Forester, 1949 to 1958.

Norton L. Marshall (Ph. D., Maryland), Assistant Professor of Plant Pathology, 1959 to present.

William R. Boggess (MF Duke), Associate Forester, 1939 to 1943.

Bruce E. Hopper, in the 1950's spent some time with the Southeastern Station and as a graduate assistant at Auburn making a survey of nematodes in pine nurseries.

Currently, Davis teaches forest pathology and conducts research while Kelley (in Botany and Microbiology) conducts forest pathology research. The others occasionally collaborate with the forest pathologists.

Research in forest tree diseases and wood products deterioration at Auburn included:

Fomes annosus: (1) Curl, Arnold, and Kelley studied the effect of cultural practices and biotic soil factors on the growth of *Fomes annosus* (Kelley and Curl 1972). Germination of spores was severely inhibited on sterilized soils from infected plots that were clear cut and then burned, or burned, disced, and planted to oats; (2) Few conidiophores of *F. annosus* were found on infected trees but large basidiocarps occurred under duff. More importantly, numerous small basidiocarps occurred in bark crevices above the duff and may be important in spread by air-borne spores (Kelley and Davis 1973).

Fusiform rust: (1) Goggans (1949) found less rust damage on slash pine in mixture with loblolly pine. He suggested using alternate rows of slash and loblolly pines and eventually removing the loblolly; (2) Goggans (1957) also made a study of the incidence of rust in 150 plots by species, age, and density of planting; (3) May and Goggans (1950) published a general description of fusiform rust, the damage it causes, and the treatment of young pine stands to limit damage; (4) Boggess and R. Stahelin (1948) found that cultivating and fertilizing pine stands increased rust infection fourfold; (5) Testing for plus strains of pine (Davis and Goggans 1968).

Soil pathogens: (1) Kelley and R. Rodriguez-Kabana (1970) determined enzymes produced by Phytophthora cinnamomi and Kelley (1975) reported significant differences in enzyme production among isolates; (2) The effect of Trichoderma on chlamydospore production by P. cinnamomi (Kelley and Rodriguez-Kabana 1974); (3) Kelley and Rodriguez-Kabana (1975) made studies over several years on the effects of potassium azide and of sodium azide on soil fungi and nematodes. Methyl bromide was more effective than the azides as a soil fumigant; (4) Hopper and Padgett (1960) made surveys of nematodes in the soil of forest nurseries.

Miscellaneous: (1) A report of a canker on eastern mistletoe caused by Hymenochaete agglutinans (Davis 1968); (2) The superiority of plastic over metal tubing for draining wetwood trees; (3) An account of Curvularia intermedius associated with seedling blight of Arizona cypress and eastern red cedar. Davis et al. (1974), summarized the information on pests of Arizona cypress seedlings and their fungicidal control; (4) Curl et al. (1959), reported phloem necrosis of elm in Alabama; (5) Davis _et al_. (1976), summarized 25 years of fence post service tests at Auburn; (7) Davis (1966) reported that the use of fungus-stained excelsior in excelsior-cement mixtures shortened the setting time.

Clemson University, Clemson, S. C.

Wesley Witcher (Ph. D. NC State), professor in the Department of Plant Pathology and Physiology, initiated forest pathology research at Clemson in 1960 and directed their research program and taught forest pathology through the 1977-78 academic year, after which forest pathology was transferred to the School of Forestry.

Among Witcher's 35 publications are a number on forest tree diseases, including: (1) _Fomes annosus_: Infection through pruned branches (Witcher and Beach 1962); spread (Witcher 1963); associated soil micro-organisms (Adams _et al_. 1964); (2) Fusarium canker of yellow-poplar (Amett and Witcher 1979); (3) _Endothia parasitica_ on live oak (Batson and Witcher 1968); (4) Occurrence reports: Oak wilt, Dutch elm disease, and Monochaetia canker of Arizona cypress and red cedar; (5) Use of benomyl on conifers (Witcher _et al_. 1973); (6) Control of needle cast on Scotch pine (Witcher _et al_. 1975).

Duke Univerisity, Durham, N. C.

Forest pathology at Duke originally was taught by Frederick A. Wolf, Professor in the Botany Department. Wolf had a primary interest in diseases of tobacco but published a number of papers on disease of other plants, including trees. Those on tree diseases were mainly mycological and included: Leaf spots on honey locust, ash, sycamore, red bud, and Chihuahua pine.

Wolf *et al*. (1938) cataloged the fungi of the Duke Forest and described their relation to tree diseases; published (Wolf and Wolf 1939) a study of *Botryosphaeria ribis* canker of willow; and published (Wolf and Barbour 1941) an account of brown spot disease of pine.

In September 1961, Willaim J. Stambaugh (Ph. D. Yale) organized a forest pathology program in the School of Forestry (later the School of Forestry and Environmental Studies). Stambaugh, still Professor of Forest Pathology, has spent much of his time in teaching but has managed the following research:

Fomes annosus: (1) Stambaugh, F. W. Cobb, R. A. Schmidt, and F. C. Krieger (1962) reported on the effect of microclimate on spore dispersal and subsequent stump invasion, based on a study made at Penn. State.

(2) The effect of soil moisture content and soil temperature on *F. annosus* infections. In the greenhouse, root infections of 2-year-old loblolly pine were higher when seedlings were subject to temporary wilting point depletions than when soil was kept near field capacity. Also, infection was higher in soils at 10 to 15°C than in soils subject to fluctuations of 15 to 38°C (Towers and Stambaugh 1968).

(3) J. D. Artman and Stambaugh (1970) found that suspending oidia of *Peniophora gigantea* in SAE 30 motor oil in a chain saw oil reservoir, was highly successful in establishing *P. gigantea* in pine stumps during a felling operation and thus restricting infections by *F. annosus*.

(4) With inoculations of severed roots of dominant red cedar in pure stands and of suppressed cedars under loblolly pines, proximal movement of the fungus was greater in roots of dominant trees and, in both classes, root penetration in the proximal direction exceeded that in the distal direction (Howell and Stambaugh 1972).

Cylindrocladium Root Rot

C. E. Cordell, A. S. Jutter, and Stambaugh (1971) made the first report of *Cylindrocladium floridanum* on yellow-poplar seedlings, on which it was causing serious mortality.

University of Florida, Gainesville, Fla.

Early Work

As at most universities, forest pathology at the University of Florida remained as stepchild of general plant pathology until the 1960's, with only insignificant research results. Forest pathology was taught by George F. Weber (Ph.D. Wisc.), Professor of Plant Pathology from 1922 to 1964. Weber maintained a primary interest in diseases of subtropical and tropical plants. His non-teaching participation in forest pathology consisted mainly of a few observations: (1) Damage caused in buildings by _Poria_ _incrassata_ (Weber 1930); (2) Mimosa wilt in Florida; (3) _Cronartium_ _quercuum_; (4) _Coleosporium_ on pine; (5) Leaf blister on oak; (6) Weber, Davidson, and Cambell (1942) described _Phychogaster_ _cubensis_ causing rot in oak and wax myrtle; (7) Reported that the chestnut blight fungus can enter chestnuts through killed twigs (Birchfield and Weber 1957).

Between Weber's retirement and the arrival of Schmidt (see below) Daniel A. Roberts (Ph.D. Cornell), Professor of Plant Pathology, taught forest pathology. In the field of forest pathology he worked on damping-off of pine seedlings in nurseries but apparently the results were never published.

Formal Forest Pathology Project

In September 1967, a forest pathology research program was initiated in the School of Forest Resources and Conservation under the direction of Robert A. Schmidt (Ph.D. Penn. St.), Associate Professor of Forest Pathology. This research program emphasizes the epidemiology of fusiform rust, including disease resistance and is one of the best coordinated and most extensive program in this field at the universities. In addition to Schmidt, the following also have been active in the program:

Charles A. Hollis (Ph. D., NY State), Assistant Professor of Forest Pathology

Ray E. Goddard (Ph. D. TX A&M), Assistant Professor of Forest Genetics

Donald L. Rockwood (Ph. D. NC State), Assistant Professor of Forest Genetics

W. L. Pritchett (Ph. D. IA State), Professor of Forest Soils

James W. Kimbrough (Ph. D. Cornell), Professor of Botany

W. H. Smith (Ph. D. MS State), Professor of Forest Nutrition

Fusiform Rust

Even though the program is relatively new, a number of significant publications on fusiform rust have appeared:

Resistance. (a) Early identification of resistant slash pine families through controlled inoculation (Goddard and Schmidt 1971); (b) Resistance results from field progeny tests (Schmidt and Goddard 1971); (c) Literature review of inoculation techniques (Schmidt 1972); (d) Predicted gains for resistance in slash pine (Rockwood and Goddard 1973); (e) Comparative performance of slash pine for resistance in high-hazard sites (Sohn *et al*. 1975); (f) Phenotypic selections of slash pine for resistance are most effective in populations exposed to high incidence of rust and significant gains can be realized as early as 3 years after roguing. (Goddard *et al*. 1975).

Distribution and incidence of rust in slash pine plantations in Florida and Georgia showed that rust was increasing with each year of planting (Schmidt *et al*. 1974).

Effect of site factors. A study of the relationship of soil and tissue nutrients, soil drainage, fertilization, and tree growth to fusiform rust incidence showed that incidence is (1) least on poorly-drained soils and highest on well-drained sites, and (2) directly correlated with extractable soil and foliar P and inversely with total N (Hollis *et al*. 1975). Greenhouse studies showed that the number of galls is positively correlated with seedling height and total amount of N, P, and K and with increases of P (Schmidt *et al*. 1972).

Other. *C*. *fusiforme* was kept alive for 6 months on a chemical medium, producing infective aeciospores (Hollis *et al*. 1972).

Other Research

A study of decline of live and laurel oaks used as an overstory in commercial ferneries (Schmidt and C. P. Seymour 1972) showed that decline was due to root pruning and wounding associated with cultivation and followed by root and butt rot.

Pitch canker also has been studied in slash pine plantations. Schmidt and E. M. Underhill (Hudson Pulp and Paper Company) reported that in 16 plots over a 3-year period, the number of cankers increased 7.6 percent per annum with an annual loss of 0.23 cords per acre (Schmidt and Underhill 1974). In 1976, George M. Blakslee (Ph. D. Duke) joined the faculty to teach forest pathology and do research on pitch canker because it had reached epiphytotic proportions in some areas of Florida.

The University of Georgia, Athens, Ga.

Julian H. Miller, Plant Pathologist and Head, Department of Plant Pathology of the University of Georgia, was interested in forest pathology throughout his long tenure, up to his retirement in 1958. He discussed forest seed bed diseases in the Southeast (J. Miller 1935) and published historical sketches of forest tree diseases of Georgia (J. Miller 1950), consisting of short paragraphs on the major and many of the minor diseases. Miller also started a catalog of Georgia fungi, including those on trees: (1) *Pyrenomycetes* (See J. Miller and Burton 1942); (2) *Ascomycetes* (J. Miller 1941); and (3) *Hypoxylon* species of the world (J. Miller 1961). He also described several new fungal species causing leaf spots on honey locust, southern red oak, and magnolia.

John S. Boyce, Jr. (PhD Duke) joined the faculty of the Department of Plant Pathology in 1961, remaining until 1966. His researches include: The rate of penetration of *Fomes annosus* in fresh pine stumps and roots (Boyce 1963); (2) A study showing there are fewer fungi in the soil around trees infected with *F. annosus* (Veech and Boyce 1964); (3) A report that phytoactin is ineffective against fusiform rust (Taylor and Boyce 1965); (4) Finding that *Peniophora* fruits in all seasons, suggesting that inoculum of *Peniophora*, as an antagonist of *F. annosus*, could be increased by felling a few pines several months prior to a thinning operation (Boyce 1966); (5) Proved that *Monochaetia* is pathogenic on Arizona cypress and red cedar (Boyce and Graves 1966); and (6) Reported *Polyporus tomentosus* var. *circinatus* was associated with basal cankers and butt and root rot of slash pine (Boyce 1967).

Currently, the Department of Plant Pathology relies mainly on the Southeastern Station pathologists for most forest tree disease research. Dwinell, Marx, T. Miller, Powers, Rowan, and Ruehle are adjunct professors or research associates. F. F. Hendrix (PhD Calif.) resigned from the Southeastern Station in 1964 to join the faculty of the Department of Plant Pathology. Hendrix teaches forest pathology and retains some interest in the mycology of *Pythium* and *Phytophthora* in forest soils, mainly in collaboration with W. A. Campbell (See Hendrix and Campbell 1973).

L. W. R. Jackson resigned from the Southeastern Station in 1946 to join the faculty of the School of Forest Resources. He continued his interest in forest tree diseases and his research publications include: (1) A description of an abiotic needle curl of shortleaf pine on dry sites (Jackson 1948). (2) Reducing damping-off of stratified and unstratified pine seeds by fungicidal dusting (Hamilton and Jackson 1951). (3) Littleleaf drastically reduces seed viability (Jackson 1952). (4) Developed grafting techniques that showed that littleleaf disease is not of viral origin (Jackson and Zak 1949). (5) Described the anatomy of fusiform rust galls (Jackson and Parker 1958). (6) Calculated that the age of a fusiform rust canker in years is about 2/3 its length in inches (Jackson 1968). (7) Both ecto- and endotrophic mycorrhizae occur on several hardwoods (Jackson and Driver 1969).

William A. Campbell (Ph.D. Penn St.), on retirement from the Southeastern Station, became a professor in the School of Forest Resources. He maintained his primary pathology interst in the mycology of soil-borne Phycomycetes. His publications in collaboration with Hendrix are listed above.

Louisiana State University, Baton Rouge, La.

For many years, forest pathology research at Louisiana State was conducted only as a side line by general plant pathologists in the Department of Plant Pathology and Botany. C. W. Edgerton (1924), Professor of Botany and Plant Pathology from 1908 to 1950, published one of the earliest accounts of Poria incrassata attack in buildings and later (Johnson and Edgerton 1936) first reported Fomes geotropus on magnolia.

A. G. Plakidas (Ph.D. Nebr), Professor of Plant Pathology from 1927 to 1960, described a new leaf spot of magnolia caused by *Isariopsis magnoliae* Plk. (Plakidas 1960) and the perfect stage (*Venturia acerina* Plk) of *Cladosporium humile* on maple (Plakidas 1942).

J. P. Hollis (Ph.D. Neb), Professor of Plant Pathology from 1954 to the present, although maintaining a primary interest in rice diseases, conducted studies on soil fumigation in pine tree nurseries. Most of this work was published jointly with T. Handsbrough (Forester) and R. G. Merrifield (Associate Pathologist) of the North Louisiana Hill Farm Experiment Station. One study was in cooperation with the Southern Station (Shoulders *et al*. 1965) These reports showed that soil fumigation would increase production by controlling root disease but the most effective fumigant, methyl bromide, was economically feasible only if a weed problem existed.

A. A. Antonopoulos (Ph.D. Colo. St.), Assistant Professor from 1969 to 1976, described the morphology of *Cronartium fusiforme* aeciospores as reveiled under the electronic microscope (Antonopoulos and Chapman 1976).

Currently forest pathology is under John P. Jones (Ph.D. GA), Assistant Professor. Jones joined the faculty in 1977. Jones' primary research interest is in forest pathology, presently nursery diseases including a study of fungicidal control of fusiform rust in cooperation with the U.S. Forest Service.

Louisiana Tech University, Ruston, La.

Forest pathology research at Louisiana Tech started in 1966 when Frederick F. Jewell (Ph.D. Wisc) left the Southern Station to become Professor of Forest Protection in the School of Forestry. Jewell has maintained a vigorous research program on *Cronartium fusiforme* and *C. quercuum*, much of it in cooperation with the Southern Station's Gulfport laboratory. His research since leaving the Southern Station is reported in 17 publications, including: (1) Resistance in pine (Jewell and Mallett 1966; Jewell and Snow 1972; Jewell and Spiers 1976), (2) Histology of rust infection (Jewell and Walker 1967; Jewell 1969; 1972, 1975), and (3) General (Peterson and Jewell 1968).

Fred Jewell is one of the most respected pathologists in the field of resistance to fusiform rust.

Mississippi State University, Mississippi State, Miss.

Forest Diseases

Lee E. Miles spent 1920-1922 at Mississippi State as Plant Pathologist, State Plant Board, before going to Alabama Polytechnic Insititute. He made copious notes on the rusts occurring in Mississippi, including *Cronartium comandrae* on southern pines. This catalog of rusts was published considerably later (Miles 1934).

About 1960, G. K. Parris of the Department of Botany and Weed Science started some research on tree diseases, but the teaching load was heavy and thus research was limited. He did, however, show that needle browning on roadside loblolly pine can be controlled by a fungicide applied with a mist blower. He also reported observations on an abiotic leaf curl of pine (Parris 1967) and on *Polyporus lucidus* on honey locust (Parris 1966).

Parris retired in June 1973 and Vernon D. Ammon (Ph.D. Mo) replaced him in October 1973. Ammon is State's first forest pathologist in the forest tree disease field. Ammon has started a research program, concentrating on two problems: (1) Sycamore anthracnose: the infection process and the selection of sycamore strains for resistance. (2) Fusiform rust: the resistance mechanism and, in cooperation with the Southern Station, the histology of different reactions when slash, loblolly, and shortleaf pines are inoculated with high and low virulent strains of _C. fusiforme_.

Forest Products Pathology

The Forest Products Utilization Laboratory at Mississippi State University was established in 1964 and has developed into one of the strongest products research institutions in the United States. In 1969, the laboratory added a forest pathologist, E. Richard Toole (Ph.D. Duke), a retiree from the Southern Station--to study the fungal deterioration of wood and wood products. Included in Toole's researches are: (1) The biodeterioration of particle board (Toole and Barnes 1974). (2) The influence of season on organisms infecting untreated pine stakes (Toole 1971). (3) Variation in decay resistance of southern pine sapwood (Toole 1970). (4) Effect of decay fungi on the micro-structure of red oak heartwood (Toole 1972). (5) A comparison of oxygen utilization and weight loss for evaluating wood preservatives in soil-block tests (Toole 1975). (6) Using crushing strength to evaluate wood preservatives (Toole 1971a). (7) Reduction in crushing strength and weight loss associated with several white and brown rotters (Toole 1971c). (8) A study showing the spores of brown-rot fungi germinate better on pine and those of white-rot fungi on gum (Toole 1971). (9) In cooperation with the Southern Station, the influence of variation in physical and chemical properties of red-oak lumber on decay (Toole 1970).

Toole retired in 1978 and Amburgey joined the staff in 1979.

North Carolina State University, Raleigh, N. C.

Although R. F. Poole, D. E. Ellis, and others had taught forest pathology for a number of years, it was not until the 1950's when Arthur Kelman (Ph.D. NC St.) became responsible for forest pathology, that an outstanding course and research program was developed. During the 1960's, forest pathology research was expanded until today North Carolina State is one of the leaders in this field. Ellis B. Cowling (Ph.D. Wisc) arrived in 1961 to work with Kelman and, in 1965, replaced him as leader of the forest pathology program.

Personnel

Until 1975, the faculty in forest pathology research and extension in the Department of Plant Pathology and the School of Forest Resources consisted of:

Fred Whitfield, 1950-1976, Extension forest pathology.

Charles S. Hodges, Jr. (Ph.D. GA), 1959-1976, Forest mycology, root and seedling diseases (with USDA).

Arthur Kelman (Ph.D. NC St), 1950-65, Physiology of tree diseases and wood deterioration.

Charles B. Davey (Ph.D. Wisc), 1965-present, Soil microbiology, mycorrhizae, tree nutrition.

Ellis B. Cowling (Ph.D. Wisc), 1965-present, Physiology of tree disease, biochemistry of wood deterioration.

Larry F. Grand (Ph.D. Wash. St.), 1967-present, Forest mycology, mycorrhizae, shade and Christmas-tree disease, soil-borne pathogens.

Michael P. Levi (Ph.D. Leeds), 1971-present, Extension wood products pathology, wood preservation.

Ronald K. Jones (Ph.D. VA Polytech), 1970-present, Extension specialist on diseases of shade trees, woody ornamentals, Christmas trees.

David M. Benson (Ph.D. Colo St), 1974-present, Soil-borne diseases, diseases of woody ornamentals, Christmas trees, shade trees.

Four adjunct professors (with the Southeastern Station) also have been on the faculty:

W. A. Campbell (Ph.D. Penn. St.), 1963-1964.

George Kuhlman (Ph.D. Ore St), 1965-present, Soil-borne pathogens and pine rusts.

Jerome Koenigs (Ph.D. Wash St), 1966-77, Physiology of wood deterioration and tree diseases.

George H. Hepting (Ph.D. Cornell), 1967-1975, Consultant on forest and wood-products pathology, air pollution.

Three visiting professors and seven postdoctoral fellows also have worked in forest pathology at North Carolina State.

Research Program

Through 1975, at least 150 publications on forest and shade tree diseases and on fungus deterioration of forest products have come from the research program. Space precludes more than a mention of the subjects covered and the major findings. Some publications in which an adjunct professor was the senior author, have been included in the section on the Southeastern Station. In addition to research, North Carolina State has an important forest pathology extension program. This program has led to many extension publications and sets of slides, or slides and tapes on pests of forest trees and wood products. None of this extension material is covered. Also, the faculty, particularly Cowling, has been involved, often with other universities, in writing sections or chapters in several recent definitive books on pathology. None of this is reviewed here.

Research Results at North Carolina State

Air pollution: North Carolina State has relied mainly on Hepting (adjunct professor) for work on the effect of air pollution on forest trees (see section on Southestern Station). However, Cowling et al. (1975) summarized the information on increased acidity of rain and snow resulting from industrial activity in North America and Europe and its effect on trees.

Fomes annosus: Research reports include: (1) Mycelial growth in inoculated lateral roots is greater in suppressed than dominant loblolly pines (T. Miller and Kelman 1964). Mycelial growth was inversely related to root carbohydrate reserve. (2) Tissue and monobasidial cultures from the United States, Canada, Japan, Europe, India, and New Zealand have optimum temperatures for growth on agar of 20 to 28°C, and the variation is not correlated with geographic origin or mean annual temperature of source (Cowling and Kelman 1964). (3) L. Shain (1967) reported that a phenol-enriched resin-soaked reaction zone forms ahead of *F. annosus* in living roots and that advance is more rapid in dead roots. (4) C. Bassett *et al.* (1967) found that formannosin, a toxic metabolite of *F. annosus*, formed in some culture media but is not detected in nature nor is *Peniophora* or *Trichoderma* affected by it. (5) J. N. Thompson *et al.* (1968) reported that *F. annosus* grew at the same rate through as over split surfaces of fresh pine sapwood bolts. The cambial zone browned in advance of the fungus and water moved from infected to uninfected regions. (6) Cowling and M.. Johansson (1970) summarized the information on the physiology of *F. annosus*.

Nematodes: Ruehle (1962) described the histopathology of nematode attack on pine roots. (2) Ruehle and J. N. Sasser (1962), from field surveys and greenhouse pathogenicity tests, reported the stunting of southern pines by nematodes. They also reported control of nematodes in outplanting sites by fumigation with the beneficial effects still evident after 5 years (Ruehle and Sasser 1964).

Fusiform rust: (1) Epidemiology. Snow, Froelich, and Popham published their researches in four articles in Phytopathology (Volume 58): Sporidia were liberated mainly during periods of high relative humidity, mainly at night and early morning; determined weather conditions conducive to infection; the effect of temperature on sporidial production. The time required for infection of pines and the effect of field and laboratory exposure. (2) Resistance: B. Kinloch and Kelman (1965) found little difference in susceptibility among progeny from infected and rust-free loblolly pines. Kinloch and R. Stonecypher (1969) observed genetic variation in susceptibility among progeny of controlled and wind pollinated families of loblolly pine planted in an area of high incidence. Zobel et al. (1971) reported on a cooperative program (23 industries and three state forest services) of expected gains from breeding for resistance, geographic variation in resistance in slash and loblolly pines, and the use of seed orchards. Stonecypher et al. (1973) reported on inheritance patterns. K. von Weissenberg (1973) described the possible use of chemical markers (as long-chain fatty acids) as indicators of resistance. (3) Miscellaneous studies: D. Bramlett and Kelman (1963) reported on the effect of cycloheximides on spore germination. T. Miller (1970) found that sporidia stored at 5`C retain viability for 8 weeks. R. L. Blair and Cowling (1974) found that seedlings are predisposed to infection by soil fertilization and site factors other than soil, but height of exposure above ground and age has little effect. D. Myren and Kelman (1975) listed the insects and fungi associated with galls, and indicated that gall tissue has lowered toughness value which contributes to wind breakage. M. Veal *et al*. (1974) reported that rust reduces yield and quality of pulp.

Miscellaneous tree diseases: (1) Pathogenicity on pines of staining species of *Ceratocystis* (Basham 1970). (2) Kelman and Gooding (1965) proved pathogenicity of *Cylindrocladium* causing root and stem rot of yellow-poplar, eastern white pine, and Fraser fir. (3) Kelman *et al*. (1960). *Exosporium* needle blight of cedar. (4) H. W. Scheld and Kelman (1963). The effect of temperature on growth, spore germination, and infection by *Phomopsis juniperovora*. (5) Mycology: Grand and others have published a number of papers on tree fungi. (6) Mycorrhizae: Marx published several papers (see Southeastern Station section for his contributions). (7) *Phytophthora cinnamomi*: Morphology and physiological characteristics of mating types (Haasis *et al*. 1964). Sporangial formation (Haasis *et al*. 1965).

Fungus deterioration of wood: North Carolina State, particularly under Cowling's direction, has assumed leadership in the field of the chemistry of wood deterioration: (1) The chemistry of lingnin deterioration (Kirk and Kelman 1965). (2) The hydrolysis of cellulose and lignocellulose materials was summarized by Cowling (1975). (3) The relationship of N and other elements in wood to decay rate. A number of studies by Cowling with W. Merrill and/or Levi were summarized by Cowling (1970) and by Basham and Cowling (1975). (4) Even though N content of wood influences decay rate, N fertilization of a forest stand does not influence the decay rate of wood cut from it (Cowling et al. 1969). (5) Some work was done on wood preservation. C. K. Chou et al. (1974) studied the hyphal uptake, toxic limits, and effect of Cu-Cr-As preservatives on colonizing wood and Levi et al (1974) found that grape plants growing next to treated stakes do not absorb these elements. Levi (1973) reported highly variable retentions of creosote in pressure treated southern pine veneer cores. (6) Some work on the genetics of wood-destroying fungi and natural decay resistance has been reported (Amburgey 1970, 1970a).

Stephen F. Austin State University, Nacogdoches, Tex.

Forest pathology at SFA is in the School of Forestry. The first forest pathologist there was Arthur F. Verrall (Ph.D. Minn), Professor of Forest Pathology from 1965 to 1970. His researches included: (1) A study of increased porocity of pine logs stored under a commercial water spray and the use of a water repellent to overcome this in lumber cut from the logs (Verrall 1970). (2) A report of a possibly new pine-oak rust (Verrall 1968a). (3) With a grant from the Southern Station, a study of some factors affecting the compatibility of decay fungi and molds (unpublished).

Thomas W. McGrath (Ph.D. Wisc) now is teaching forest pathology at SFA.

Texas A&M University, College Station, Tex.

Eugene P. Van Arsdel (Ph.D. Wisc) left the North Central Forest Experiment Station in the late 1960's to become Associate Professor of forest pathology in the Plant Sciences Department of Texas A&M. The first major problem facing him in Texas was the decline of live oak, which is an important tree on the fringe of the prairie. R. S. Halliwell (Associate Professor of plant pathology 1966) had reported the association of a Cephalosporium with the decline. Van Arsdel and Halliwell (1970) described decline as a complex of which Cephalosporium is a major component. Cephalosporium wilt can be separated from such damage as that caused by soil fill, excavation, and over fertilization, by the use of infra-red photography

(Van Arsdel and Bush 1970). Van Arsdel and Bush determined the uptake of benomyl solution in sycamore, live oak, and post oak as a possible wilt control (Van Arsdel et al. 1972).

Other researches reported by Van Arsdel includes: (1) The life cycle and spread of ash rust (Van Arsdel and Chitzonidis 1970). (2) Poplar rust. Chitzonidis and Van Arsdel (1970) suggest that high summer temperatures kill most of the rust and that it is reintroduced annually from the North as weather cools in the fall. Van Arsdel also is working on some of the epidemiology phases of fusiform rust in East Texas; some of this is in cooperation with the Southern Station. He had studied epidemiology of white pine blister rust in the North.

SOUTHWIDE FOREST DISEASE WORKSHOP

At George Hepting's suggestion, the pathologists at the Southern and Southeastern Stations met in Athens, Ga., in 1953 for an in-service exchange of ideas, and these meetings were continued in alternate years. Occasionally, outside pathologists were invited but primarily the meetings were to coordinate the research programs of the two Stations.

By 1960, industry had greatly expanded forest management in the South and was feeling the serious impact of diseases. As a result, two groups of interested foresters, mostly from industry and schools met in 1960 to discuss what could be done to stimulate financial support for research in the insect and disease fields by Federal and State governments and by industry. These meetings led to the organization of the Southern Forest Disease and Insect Research Council, with strong affiliation with the Southern Pulpwood Association. An interim committee, chaired by T. E. Maki of North Carolina State University, was formed in 1962 to study research needs. One of this committee's suggestions was that as many as possible of the South's forest pathologists meet every few years to coordinate research. As a result, the in-service meetings were expanded in 1962, to include pathologists and interested foresters in industry, state governments, and schools as well as the pathologists of the Southeastern and Southern Stations.

By 1970, as many as 90 people attended these workshops. Meetings, now at 18-month intervals, are proving valuable in exchanging ideas on problems and on research underway or planned. They also are a means of getting research results to practicing forest managers. At Hepting's suggestion, a steering committee system was formed to insure continuity and integrity of the workshops.

With the expanded attendance, the workshop has lost much of its original purpose as a coordinating forum for the two Stations. Such coordination, however, is being accomplished by frequent exchanges between the project leaders of the two Stations, by joint studies where problems overlap Station boundaries, and by personal contacts among Federal, State, and industry personnel. This has done much to increase mutual trust and understanding and to increase cooperative efforts.

SUMMARY:

AN EVALUATION OF FOREST PATHOLOGY RESEARCH IN THE SOUTH AND SOUTHEAST[1]

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[1] This is discussed more fully country wide by George Hepting (1970) and by Hepting and Cowling (1977).

The forest pathologists at the Southern and Southeastern Forest Experiment Stations can be proud of their research because of beneficial effect on forest management and the use of forest products. The first half century of this research consisted largely of practical field research directed at solving the economically important disease problems facing forest managers and wood users. For several decades this left little time for the small number of pathologists involved to delve into more basic research. Some of the beneficial effects of this research on southern forestry and wood utilization are:

Estimating Losses

Forest pathologists prepared the disease loss figures in the Timber Resources Review of 1958. The disease loss figures helped: (a) To estimate how much our future timber requirement deficiencies might be made up by better disease control, and (b) to determine research needs.

Reducing Losses

Some outstanding examples of research that has had an important financial impact are: (a) The determination of the rate of southward spread of chestnut blight, the rate of deterioration of blight-killed trees, and the rate of reduction of tannin content of such trees gave commercial interests the data needed to determine rate of use or salvage and to develop substitutes for chestnut products. (b) The rate of decay in southern and Appalachian hardwoods following fire injury; that entering through branch stubs; and that of logging slash furnishes the information needed to set harvesting and salvaging schedules that minimize loss from decay. (c) The finding and propogating of lines of eastern white pine resistant to the emissions from soft-coal burning power plants permits growing white pine in areas where air-pollution had threatened to eliminate this species. (d) Soil fumigation and fungicidal sprays developed to control root rot, brown spot, and fusiform rust in nurseries greatly increases yields and quality of seedlings and, in some cases, prevented abandonment of nurseries where root rot was critical. (e) Controls for cone rust greatly increase seed yields in orchards and genetic research. (f) A soil rating scale permits easy determination of sites where shortleaf pine can be grown without important losses from little leaf disease. (g) A site classification for southern pines, the effect of season of cutting, and stump treatments lessen losses from Fomes annosus.

In the field of products pathology, research developed: (a) Mechanically-applied chemical dips to protect air-seasoning lumber from stain, mold, and decay. (b) Simple preservative treatments to protect wood ammunition boses from decay during open storage. (c) Minor changes in building designs and simple preservative treatments that prevent decay associated with rain seepage, condensation, and water-conducting fungi.

Although I cannot assign definite monetary saving to southern forestry and wood utilization resulting from forest pathology research conducted at the Southern and Southeastern Stations, there is no doubt that it is more than the total expenditures for forest pathology research at the two stations up to 1960. The results certainly point to the value of research and the need for a continuing vigorous research program in the fields of forest tree diseases and wood products protection.

The above evaluation is based on research at the two Federal Forest Experiment Stations. Recently, the southern universities also are making important contributions to forest pathology research so there is every reason to believe that ongoing research by Federal, State, and private agencies will provide economical controls for the future disease problems of southern forest managers and wood users.

Status of Forest Pathologists

Despite the contributions they have made, forest pathologists for a long time were in the unenviable position of being "outsiders", foresters called us plant pathologists and plant pathologists called us foresters. At the 1961 annual meeting of the American Phytopathological Society (APS) in Biloxi, Miss., George Hepting gave a talk on forest pathologists and their work, urging using the APS as their major forum. Two years later, the APS established a forest pathology subject matter committee and, since then, a section on forest diseases has been included in the APS annual meetings, resulting in a many-fold increase in the number of forest disease papers at the annual meetings. The stature of forest pathologists also was increased by forest pathologists participating in the meetings of the International Congress of Plant Pathologists. These recognitions of the professional standing of forest pathologists are a result of their contributions to the forest and wood-using industries and to the science of phytopathology.

LITERATURE CITED

Adams, J.T., Jr., W. Witcher, and C.L. Lane.
1964. Microorganisms in soil from *Fomes annosus* infected pine stands. Plant Dis. Rep. 48:114-118.

Aist, J.R. and C.L. Wilson.
1967. Nuclear behavior in the vegetative hyphae of *Ceratocystis fagacearum*. Amer. J. Bot. 54:89-104.

Aist, J.R. and C.L. Wilson.
1968. Interpretation of nuclear division figures in vegetative hyphae of fungi. Phytopathology 58:876-877.

Amburgey, T.L.
1970. Genetic control of basidiospore formation by isolates of *Lenzites trabea*. Phytopathology 60:951-954.

Amburgey, T.L.
1970a. Relationship of capacity to cause decay to other physiological traits in isolates of *Lenzites trabea*. Phytopathology 60:955-960.

Amburgey, T.L.
1974. Organisms causing discoloration and deterioration of asphalt roofing shingles. For. Prod. J. 24(6):52-54.

Amburgey, T.L.
1976. Observations on the soil-block and agar-block methods of evaluating wood decay. Mat. und Organ. 11:273-277.

Amburgey, T.L.
1977. Fungitoxicity of pentachlorophenol having reduced impurities. For. Prod. J. 27(11):18-19.

Amburgey, T.L., F.A. Carter, and D.R. Roberts.
1978. Resistance of wood from paraquat-treated trees to termites and the fungus *Gloeophyllum trabeum*. Wood Sci. 10:187-192.

Amburgey, T.L. and B.R. Johnson.
1978. Effect of ammonium hydroxide on thiamine and available micronutrients in ponderosa pine sapwood. Phytopathology 68:951-954.

Amett, J.D. and W. Witcher.
1974. Histochemical studies of yellow poplar infected with *Fusarium solani*. Phytopathology 64:414-418.

Antonopoulos, A.A. and R.L. Chapman.
1976. Morphology of *Cronartium fusiforme* aeciospores: A light and scanning electron microscopic study. Bot. Gaz. 137:285-289.

Armentrout, V.N., G.G. Smith, and C.L. Wilson.
1968. Spherosomes and mitochondria in the living fungal cell. Amer. J. Bot. 55:1062-1067.

Artman, J.D. and W.J. Stambaugh.
1970. A practical approach to the application of *Peniophora gigantea* for control of *Fomes annosus*. Plant Dis. Rep. 54:799-802.

Barham, R.O., D.H. Marx, and J.L. Ruehle.
1974. Infection of ectomycorrhizae and nonmycorrhizal roots of shortleaf pine by nematodes and *Phytophthora cinnamomi*. Phytopathology 64:1260-1264.

Basham, H.G.
1970. Pathogenicity and development of wilt in loblolly pine inoculated with some blue-stain fungi in the genus *Ceratocystis*. Phytopathology 60:750-754.

Basham, H.G. and E.B. Cowling.
1975. Distribution of essential elements in forest trees and their role in wood deterioration. Mat. und Organ. 3:155-165.

Bassett, C., R.T. Sherwood, J.A. Kepler, and P.B. Hamilton.
1967. Production and biological activity of fomannosin, a toxic sesquiterpene metabolite of the fungus *Fomes annosus*. Phytopathology 57:1046-1052.

Batson, W.E., Jr. and W. Witcher.
1968. Live oak canker caused by *Endothia parasitica*. Phytopathology 58:1473-1475.

Baxter, D.V. and L.S. Gill.
1931. Deterioration of chestnut in the Southern Appalachians. U.S. Dep. Agric. Tech. Bull. 257,22p.

Berry, C.R. and G.H. Hepting.
1964. Injury to eastern white pine by unidentified atmospheric constituents. For. Sci. 10:2-13.

Berry, C.R. and L.A. Ripperton.
1963. Ozone, a possible cause of white pine emergence tipburn. Phytopathology 53:552-557.

Bethune, J.E. and G.H. Hepting.
1963. Pitch canker damage to south Florida slash pine. J. For. 61:517-519, 522.

Birchfield, W. and G.F. Weber.
1957. Blight fungus invades chestnut from killed twigs. Plant Dis. Rep. 41:359-361.

Blair, R.L. and E.B. Cowling.
1974. Effects of fertilization, site, and vertical position on the susceptibility of loblolly pine seedlings to fusiform rust. Phytopathology 64:761-762.

Boggess, W.R. and R. Stahelin.
1948. The incidence of fusiform rust in slash pine plantations receiving cultural treatments. J. For. 46:683-685.

Boyce, J.S., Jr.
1954. Mat formation by the oak wilt fungus on felled versus standing trees. Plant Dis. Rep. 38:676-677.

Boyce, J.S., Jr.
1958. Needle cast of southern pines. U.S. Dept. Agric. For. Serv. For. Pest Leaflet 28,4p.

Boyce, J.S., Jr.
1959. Oak wilt spread in control-treated and untreated counties in the southern Appalachians. J. For. 57:660-661.

Boyce, J.S., Jr.
1962. *Fomes annosus* in white pine in North Carolina. J. For. 60:553-557.

Boyce, J.S., Jr.
1963. Growth of *Fomes annosus* into slash pine stumps after top inoculation. Plant Dis. Rep. 47:218-221.

Boyce, J.S., Jr.
1966. Sporulation of *Peniophora gigantea* with reference to control of annosus root rot. For. Sci. 12:2-7.

Boyce, J.S., Jr.
1967. Red root and butt rot in planted slash pines. J. For. 65:493-494.

Boyce, J.S., Jr. and K.H. Garren.
1953. Compatibility types of the oak wilt fungus in 23 Appalachian trees. Phytopathology 43:644-645.

Boyce, J.S., Jr. and A.A. Graves.
1966. Monochaetia canker on Arizona cypress in Georgia and South Carolina. Plant Dis. Rep. 50:482-483.

Bramlett, D.L. and A. Kelman.
1963. The influence of cycloheximide on germination of spores of *Cronartium fusiforme*. Plant Dis. Rep. 47:1024-1028.

Bryan, W.C.
1960. Losses from defect in Piedmont hardwoods. U.S. Dep. Agric. For. Serv. Southeast. For. Exp. Sta. Paper 109,31p.

Bryan, W.C.
1965. Testing shortleaf pine seedlings for resistance to infection by *Phytophthora cinnamomi*. U.S. Dept. Agric. For. Serv. Res. Notes SE-50, 4p.

Bryan, W.C. and B. Zak.
1961. Synthetic culture of mycorrhizae of southern pines. For. Sci. 7:123-129.

Bushaber, J.A., C.L. Wilson, and J.R. Aist.
1967. Asexual nuclear behavior of some plant-pathogenic fungi. Phytopathology 57:43-46.

Campbell, W.A., O.L. Copeland, and G.H. Hepting.
1953. Managing shortleaf pine in littleleaf disease areas. U.S. Dep. Agric. For. Serv. SE Sta. Pap. 25.

Campbell, W.A. and O.L. Copeland.
1954. Littleleaf disease of shortleaf and loblolly pines. U.S. Dep. Agric. Circ. 940,41p.

Campbell, W.A., S.P. Darby, and J.C. Barber.
1962. Fusiform rust, an obstacle to the establishment of grafted slash and loblolly pine seed orchards. Ga. For. Res. Pap. 11,5p.

Campbell, W.A. and A.F. Verrall.
1963. *Phytophthora cinnamomi* associated with Lawson cypress mortality in Louisiana. U.S. Dep. Agric. Plant Dis. Rep. 47:808.

Carpenter, B.E., Jr. and E.R. Toole.
1963. Sprinkling with water protects hardwood logs in storage. South. Lumberman 207 (2576):25-26.

Chapman, H.H.
1926. Factors determining natural reproduction of longleaf pine on cut-over lands in LaSalle Parish, La. Yale Univ. School For. Bull. 16,44p.

Chitzonidis, A. and E.P. Van Arsdel.
1970. Autumn introduction and winter survival of poplar rust on the Texas coastal plain. Phytopathology 60:502.

Chow, C.K., R.D. Preston, and M.P. Levi.
1974. Fungitoxic action of a copper-chromium-arsenate wood preservative. Phytopathology 64:335-341.

Clapper, R.B.
1954. Stimulation of pine oleoresin flow by fungus inoculation. Econ. Bot. 8:269-284.

Cobb, F.W.
1957. Pitch streak-a disease of turpentined slash pine. Naval Stores Rev. 67(9):4,5.

Cooper, D.T. and T.H. Filer, Jr.
1976. Resistance to septoria leaf spot in eastern cottonwood. Plant Dis. Rep. 60:812-814.

Copeland, O.L., Jr. and R.G. McAlpine.
1962. Soil characteristics associated with spot die-out in loblolly pine plantations. For. Sci. 8:12-15.

Cordell, C.E., A.S. Jutter, and W.J. Stambaugh.
1971. *Cylindrocladium floridanum* causes severe mortality of seedling yellow-poplar in a North Carolina nursery. Plant Dis. Rep. 55:700-702.

Cowling, E.B.
1970. Nitrogen in forest trees and its role in wood deterioration. Acta Universitatis Upsalienses 164:1-19.

Cowling, E.B.
1975. Physical and chemical constraints in the hydrolysis of cellulose and lignocelluloseic materials. Biotechnology and Bioengineering Symp. 5:163-181.

Cowling, E.B., B. Dillner, and S. Rydholm.
1969. Comparative decay susceptibility of sapwood in nitrogen-fertilized and nonfertilized stands of Norway spruce and Scots pine. Phytopathology 50:1022.

Cowling, E.B., A.S. Heagle, W.W. Heck.
1975. The changing acidity of precipitation. Phytopathology News 9(10):5.

Cowling, E.B. and M. Johansson.
1970. Physiology of Fomes annosus. Proc. 3rd Internal. Conf. on Fomes annosus. p192-205.

Cowling, E.B. and A. Kelman.
1964. Influence of temperature on growth of Fomes annosus isolates. Phytopathology 54:373-378.

Curl, E.A. and M.M. Arnold
1964. Influence of substrate and microbial interactions on growth of Fomes annosus. Phytopathology 54:1486-1487.

Curl, E.A., L.L. Hyche, and N.L. Marshall.
1959. An outbreak of phloem-necrosis in Alabama. Plant Dis. Rep. 43:1245-1246.

Czabator, F.J.
1971. Fusiform rust of southern pines--A critical review. U.S. Dep. Agric. For. Serv. Res. Pap. SO-65, 39p.

Czabator, F.J. and H. Enghardt.
1959. Nursery-infected seedlings develop fusiform rust cankers after outplanting. Tree Planters' Notes 37:23-25.

Davidson, R.W., W.A. Campbell, and G.F. Weber.
1942. Ptychogaster cubensis, a wood-decaying fungus of southern oaks and waxmyrtle. Mycologia 34:142-149.

Davis, T.C.
1966. Effect of blue stain on setting of excelsior-cement mixtures. For. Prod. J. 16(6):49-50.

David, T.C.
1968. Hymenochaete agglutinans on Phorodendron flavescens. Plant Dis. Rep. 52:496-499.

Davis, T.C., H.D. Beals, K.W. Livingston, and T.R. McIntyre.
1976. Fence post service tests at Auburn University-A twenty-five year report. Ala. Agric. Exp. Sta./Auburn Univ. For. Dep. Series No. 8,8p.

Davis, T.C., Jr. and J.F. Goggans.
1968. Testing plus pines for fusiform rust resistance. Auburn Univ. Agric. Exp. Sta. Highlights of Agric. Res. 15(3):10.

David, T.C., J.F. Goggans, and R.J. Meier.
1974. Pest control problems encountered in seedling production of Arizona cypress. Tree Planters' Notes 25(2):7-10.

DeGroot, R.C. and H.W. Scheld.
1971. Biodegradation of sapwood from southern pine logs stored under a continuous water spray. For. Prod. J. 21(10):53-55.

DeGroot, R.C.
1971a. Interaction between wood decay fungi and *Streptomyces* species. Bull. Torrey Bot. Club 98:336-339.

DeGroot, R.C. and H.W. Scheld.
1973. Permeability of sapwood in longleaf pine logs stored under continuous water spray. For. Prod. J. 23(4):43-46.

Diller, J.D. and R.B. Clapper.
1965. A progress report on attempts to bring back the chestnut tree in Eastern United States. J. For. 63:186-188.

Dwinell, L.D.
1971. Interaction of *Cronartium fusiforme* and *Cronartium quercuum* with *Quercus velutina*. Phytopathology 61:1055-1058.

Dwinell, L.D.
1974. Susceptibility of southern oaks to *Cronartium fusiforme* and *Cronartium quercuum*. Phytopathology 64:400-403.

Dwyer, W.W., Jr.
1951. *Fomes annosus* on eastern redcedar in two Piedmont forests. J. For. 49:259-262.

Edgerton, C.W.
1924. "Dry rot" in buildings and building material. Louisiana State Univ. Louisiana Bull. 190,12p.

Eleuterius, L.N.
1968. Morphology of *Cronartium fusiforme* in *Quercus nigra*. Phytopathology 58:1487-1492.

Eleuterius, L.N. and G.A. Snow.
1964. Caulicolous telia and uredia of *Cronartium fusiforme*. Plant Dis. Rep. 48:366.

Englerth, G.H., J.S. Boyce, Jr., and E.R. Roth.
1956. Longevity of the oak wilt fungus in red oak lumber. For. Sci. 2:2-6.

Eppstein, D.A. and F.H. Tainter.
1976. Temperature and pH optima for germination of Arkansas collections of comandra blister rust aeciospores. Can. J. For. Res. 6:459-461.

Eppstein, D.A. and F.H. Tainter.
1976a. Germination self-inhibitor from Cronartium comandrae aeciospores. Phytopathology 66:1395-1397.

Filer, T.H., Jr.
1973. Supression of elm phloem necrosis symptoms with tetracycline antibiotics. Plant Dis. Rep. 57:341-343.

Filer, T.H., Jr.
1973a. Pressure apparatus for injecting chemicals into trees. Plant Dis. Rep. 57:338-341.

Filer, T.H., Jr.
1975. Mycorrhizae and soil microflora in a green-tree reservoir. For. Sci. 21:36-39.

Filer, T.H., Jr., D.T. Cooper, R.J. Collins, and R. Wolfe.
1975. Survey of sycamore plantations for canker, leaf scorch, and dieback. Plant Dis. Rep. 59:152-153.

Filer, T.H., F.I. McCracken, C.A. Mohn, and W.K. Randall.
1971. Septoria canker on nursery stock of Populus deltoides. Plant Dis. Rep. 55:460-463.

Filer, T.H. and E.R. Toole.
1966. Sweetgum, mycorrhizae and some associated fungi. For. Sci. 12:432-437.

Filer, T.H., Jr. and E.R. Toole.
1968. Effect of methyl bromide on mycorrhizae and growth of sweetgum seedlings. Plant Dis. Rep. 52:483-485.

Foster, A.A.
1961. Control of black root rot of pine seedlings by soil fumigation in the nursery. Ga. For. Res. Council Rep. 8,5p.

Foster, A.A. and R.P. Harrison.
1957. Seedling losses in Arizona cypress. Tree Planters' Notes 29:20-21.

Foster, A.A. and D.W. Krueger.
1961. Protection of pine seed orchards and nurseries from fusiform rust by timing ferbam sprays to coincide with infection periods. Ga. For. Res. Pap. 1,4p.

Froelich, R.C., T.R. Dell, and C.H. Walkinshaw.
1965. Factors associated with occurrence of Fomes annosus in pine plantations. Phytopathology 55:1058-1059.

Froelich, R.C., T.R. Dell, and C.H. Walkinshaw.
1966. Soil factors associated with Fomes annosus in the Gulf States. For. Sci. 12:356-361.

Froelich, R.C., C.S. Hodges, Jr., and S.S. Sackett.
1978. Prescribed burning reduces severity of annosus root rot in the South. For. Sci. 24:93-100.

Froelich, R.C., E.G. Kuhlman, C.S. Hodges, M.J. Weiss, and J.D. Nichols.
1977. Fomes annosus root rot in the South. Guidelines for prevention U.S. Dept. Agric. For. Serv. South. For. Exp. Sta., Southeast. For. Exp. Sta., State and Private For. unnumbered bulletin 17p.

Froelich, R.C. and J.D. Nicholson.
1973. Spread of Fomes annosus reduced by heavy application of sulfur. For. Sci. 19:75-76.

Froelich, R.C. and G.A. Snow.
1965. Pine trees near power substations demaged by urea herbicides. Plant Dis. Rep. 49:970-971.

Gilespie, W.H. and C.L. Wilson.
1960. Limited saprophytic survival of the oak wilt fungus Ceratocystis fagacearum (Bretz) Hunt. Plant Dis. Rep. 44:687-689.

Goddard, R.E. and R.A. Schmidt.
1971. Early identification of fusiform rust resistant slash pine families through controlled inoculation. Proc. Eleventh Conf. South. For. Tree Improve. p.31-36.

Goddard, R.E., R.A. Schmidt, and F.V. Linde.
1975. Effect of differential selection pressure on fusiform rust resistance in phenotypic selections of slash pine. Phytopathology 65:336-638.

Goggans, J.F.
1949. Cronartium fusiforme on slash and loblolly pine in the Piedmont Region of Alabama. J. For. 47:978-980.

Goggans, J.F.
1957. Southern fusiform rust. Ala. Polytech Inst. Agric. Exp. Sta. Bul. 304,19p.

Gooding, G.V., Jr.
1964. Effect of temperature on growth and survival of *Fomes annosus* in freshly cut pine bolts. Phytopathology 54:893-894 (abst.)

Gooding, G.V., Jr., C.S. Hodges, and E.R. Ross.
1966. Effect of temperature on growth and survival of *Fomes annosus*. For. Sci. 12:325-333.

Gooding, G.V., Jr. and H.R. Powers, Jr.
1965. Serological comparison of *Cronartium fusiforme*, *C. quercuum*, and *C. Ribicola* by immunodiffusion tests. Phytopathology 55:670-674.

Gravatt, G.F. and R.P. Marshall.
1926. Chestnut blight in the southern Appalachians. U.S. Dep. Agric. irc. 370, 11p.

Graves, A.H.
1913. Notes on diseases of trees in the southern Appalachians. Phytopathology 3:129-139.

Graves, A.H.
1914. Notes on diseases of trees in the southern Appalachians. Phytopathology 4:63-72.

Griffin, B.R. and C.L. Wilson.
1967. Asexual nuclear behavior and formation of conidia in *Fomes annosus*. Phytopathology 57:1176-1177.

Haasis, F.A., R.R. Nelson, and D.H. Marx.
1964. Morphological and physiological characteristics of mating types of *Phytophthora cinnamomi*. Phytopathology 54:1146-1151.

Haasis, F.A., R.R. Nelson, and D.H. Marx.
1965. Occurrence of mating types in *Phytophthora cambivora*. J. Elisha Mitchell Sci. Soc. 75:76.

Halliwell, R.S.
1966. Association of *Cephalosporium* with a decline of oak in Texas. Plant Dis. Rep. 50:75-78.

Hamilton, J.R. and L.W.R. Jackson.
1951. Treatment of shortleaf pine and loblolly pine seed. Plant Dis. Rep. 35:274-276.

Hare, R.C. and G.A. Snow.
1976. Two systemic fungicides show promise for control of fusiform rust. Plant Dis. Rep. 60-530-531.

Hedgcock, G.G., G.F. Gravatt, and R.P. Marshall.
1925. Polyporus schweinitzii Fr. on Douglas-fir in the eastern United States. Phytopathology 15:568-569.

Hedgcock, G.G. and Siggers, P.V.
1949. A comparison of the pine-oak rusts. U.S. Dep. Agric. Tech. Bull. 978.30p.

Hendrix, F.F. and W.A. Campbell.
1973. Pythiums as plant pathogens. Ann. Rev. Phytopath. 11:77-98.

Hendrix, F.F., Jr. and E.G. Kuhlman.
1964. Root infection of Pinus elliottii by Fomes annosus. Nature 201(4914):55-56.

Henry, B.W.
1953. A root rot of southern pine nursery seedlings and its control by soil fumigation. Phytopathology 43:81-88.

Henry, B.W.
1954. Sporulation by the brown spot fungus on longleaf pine needles. Phytopathology 44:385-386.

Henry, B.W. and T.E. Bercaw.
1956. Shortleaf-loblolly hybrid pines free of fusiform rust after 5 years' exposure. J. For. 54:779.

Henry, B.W. and O.O. Wells.
1967. Variation in brown-spot infection of longleaf pine from several geographic sources. U.S. Dep. Agric. For. Serv. Res. Note SO-52,4p.

Hepting, G.H.
1935. Decay following fire in young Mississippi delta hardwoods. U.S. Dep. Agric. Tech. Bull. 494,32p.

Hepting, G.H.
1939. A vascular wilt of the mimosa tree. U.S. Dep. Agric. Circ. 535,11p.

Hepting, G.H.
1941. Prediction of cull following fire in Appalachian oaks. J. Agric. Res. 62:109-120.

Hepting, G.H.
1941a. Eastern forest tree diseases in relation to stand improvement. Civ. Cons. Corps For. Publ. 2,26p.

Hepting, G.H.
1944. Preventing decay in wood aircraft. Aero Digest 44(4):126-128.

Hepting, G.H.
1944a. Sapstreak, a new killing disease of sugar maple. Phytopathology 34:1069-1076.

Hepting, G.H.
1945. Decay and staining of southern pine pulpwood. Paper Ind. 27:379-382.

Hepting, G.H.
1947. Stimulation of oleoresin flow in pines by a fungus. Science 105:209.

Hepting, G.H.
1955. The current status of oak wilt in the United States. For. Sci. 1(2):95-103.

Hepting, G.H.
1955a. A southwide survey for sweetgum blight. Plant Dis. Rep. 39:261-265.

Hepting, G.H.
1957. A rust on Virginia pine and Buckleya. Mycologia 49:896-899.

Hepting, G.H.
1964. Forest pathology in the southern Appalachians, 1900-1940. For. Hist. 8.11-13.

Hepting, G.H.
1967. The INTREDIS register for literature retrieval in forest pathology. Proc. XIV IUFRO Congress. Section 24:385-387.

Hepting, G.H.
1970. The case for forest pathology. J. For. 68:78-81.

Hepting, G.H.
1971. Diseases of forest and shade trees of the United States. U.S. Dep. Agric. For. Serv. Agric. Handb. 386, 658p.

Hepting, G.H.
1971a. Climate and forest diseases. In: Man's impact on terrestrial and oceanic ecosystems, pp203-226. Eds. W.H. Mathews, F.E. Smith, and E.D. Goldberg. MIT Press.

Hepting, G.H.
1971b. Air pollution and trees. In: Man's impact on terrestrial and oceanic ecosystems, pp116-129. (See Hepting 1971a for citation)

Hepting, G.H. and C.R. Berry.
1961. Differentiating needle blights of white pine in the interpretation of fume damage. Int. J. Air and Water Pollution 4:101-105.

Hepting, G.H. and D.J. Blaisdell.
1936. A protective zone in red gum fire scars. Phytopathology 26:62-67.

Hepting, G.H. and A.D. Chapman.
1938. Losses from heartrot in two shortleaf and loblolly pine stands. J. For. 36:1193-1201.

Hepting, G.H. and E.B. Cowling.
1977. Forest pathology: Unique features and prospects. Ann. Rev. Phytopathol. 12:431-450.

Hepting, G.H. and R.W. Davidson.
1935. Some leaf and twig diseases of hemlock in North Carolina. Plant Dis. Rep. 19:308-309.

Hepting, G.H. and R.W. Davidson.
1937. A leaf and twig disease of hemlock caused by a new species of Rosellinia. Phytopathology 27:305-310.

Hepting, G.H. and A.A. Downs.
1944. Root and Butt rot in planted white pine at Biltmore, North Carolina. J. For. 42:119-123.

Hepting, G.H., K.H. Garren, and P.W. Warlick.
1940. External features correlated with top rot in Appalachian oaks. J. For. 38:873-876.

Hepting, G.H. and G.G. Hedgcock.
1937. Decay in merchantable oak, yellow poplar, and basswood in the Appalachian region. U.S. Dep. Agric. Tech. Bull. 570, 30p.

Hepting, G.H. and G.M. Jemison.
1950. A cure for littleleaf disease. Amer. For. 56(11):20-22.

Hepting, G.H. and E.R. Roth.
1950. The fruiting of heartrot fungi on felled trees. J. For. 48:332-333.

Hepting, G.H. and E.R. Roth.
1953. Host relations and spread of the pine pitch canker disease. Phytopathology 43:475 (abst.).

Hepting, G.H., E.R. Roth, and R.F. Luxford.
1942. The significance of the discolorations in aircraft veneers: yellow-poplar. U.S. Dep. Agric. Bur. Plant Ind., Soils, and Agric. Eng. For. Path. Special Release 1375,8p.

Hepting, G.H., E.R. Roth, and B. Sleeth.
1949. Discolorations and deçay from increment borings. J. For. 47:366-370.

Hepting, G.H. and E.R. Toole.
1939. The hemlock rust caused by Melampsora farlowii. Phytopathology 29:463-473.

Hepting, G.H., E.R. Toole, and J.S. Boyce, Jr.
1952. Sexuality in the oak wilt fungus. Phytopathology 42:438-442.

Hodges, C.S.
1958. The effect of fumigation on the relative abundance of soil microorganisms. Assoc. South Agric. Workers Proc. 1958:222-223.

Hodges, C.S.
1961. Freezing lowers survival of three species of southern pines. Tree Planters' Notes 47:23-24.

Hodges, C.S.
1962. Fungi isolated from southeastern forest tree nursery soils. Mycologia 54:221-229.

Hodges, C.S.
1962a. Black root rot of pine seedlings. Phytopathology 52:210-219.

Hodges, C.S.
1969. Relative susceptibility of loblolly, longleaf, and slash pine roots to infection by Fomes annosus. Phytopathology 59:1031 (abst.)

Hodges, C.S.
1969a. Modes of infection and spread of Fomes annosus. Ann. Rev. Phytopath. 7:247-266.

Hodges, C.S.
1970. Evaluation of stump treatment chemicals for control of Fomes annosus. Proc. Third Internat. Conf. on Fomes annosus p43-53.

Hodges, C.S. and H.J. Green.
1961. Survival in the plantation of eastern redcedar seedlings infected with Phomopsis blight in the nursery. Plant Dis. Rep. 45:134-136.

Hollis, C.A., R.A. Schmidt, and J.W. Kimbrough.
1972. Axenic culture of Cronartium fusiforme. Phytopathology 62:1417-1419.

Hollis, C.A., W.H. Smith, R.A. Schmidt, and W.L. Pritchett.
1975. Soil and tissue nutrients, soil drainage, fertilization, and tree growth as related to fusiform rust incidence in slash pine. For. Sci. 21:141-148.

Hopper, B.E.
1958. Plant-parasitic nematodes in the soils of Southern forest nurseries. Plant Dis. Rep. 42:308-314.

Hopper, B.E. and W.H. Padgett.
1960. Relationship of nemas (nematodes) with root rot of pine seedlings at the E.A. Hauss State Forest Nursery, Atmore, Alabama. Plant Dis. Rep. 44:258-259.

Howell, F.C. and W.J. Stambaugh.
1972. Rates of pathogenic and saprophytic development of Fomes annosus in roots of dominant and suppressed eastern redcedar. Plant Dis. Rep. 56:987-990.

Humphrey, C.J.
1923. Decay of lumber and building timbers due to Poria incrassata (B. and C.) Burt. Mycologia 15:258-277.

Humphrey, C.J. and L.E. Miles.
1925. Dry-rot in buildings and stored materials and how to combat it. Ala. Polytech. Inst. Circ. 78,28p.

Jackson, L.W.R.
1947. Method for differential staining of mycorrhizal roots. Science 105:291-292.

Jackson, L.W.R.
1948. "Needle curl" of shortleaf pine seedlings. Phytopathology 30:1028-1029.

Jackson, L.W.R.
1952. Influence of littleleaf on quality of shortleaf pine seed. Phytopathology 42:57.

Jackson, L.W.R.
1968. Growth of fusiform branch cankers on loblolly and slash pine. Naval Stores Rev. 78(4):6-7.

Jackson, L.W.R. and C.H. Driver.
1969. Morphology of mycorrhizae on deciduous forest tree species. Castanea 34:230-235.

Jackson, L.W.R. and J.N. Parker.
1958. Anatomy of fusiform rust galls on loblolly pine. Phytopathology 48:637-640.

Jackson, L.W.R. and B. Zak.
1949. Grafting methods used in studies of the littleleaf disease of shortleaf pine. J. For. 47:904-908.

Jemison, G.M. and G.H. Hepting.
1949. Timber stand improvement in the Southern Appalachian region. U.S. Dept. Agric. For. Serv. Misc. Publ. 693, 80p.

Jewell, F.F.
1957. Preventing cone rust on slash pine by pollination techniques used in breeding programs. Phytopathology 47:241-242.

Jewell, F.F.
1958. Cronartium fusiforme extent below slash pine branch cankers. Phytopathology 48:394 (abst.)

Jewell, F.F.
1960. Inoculation of slash pine seedlings with Cronartium fusiforme. Phytopathology 50:48-51.

Jewell, F.F.
1960a. New pine hosts for southern fusiform rust. Plant Dis. Rep. 44:673.

Jewell, F.F.
1969. Evidence of hyphal growth of Cronartium quercuum in the pine host cambium. Plant Dis. Rep. 53:793-794.

Jewell, F.F.
1972. A comparison of Cronartium fusiforme and C. quercuum in pine. Phytopathology 62:767.

Jewell, F.F.
1975. Characteristics of *Cronartium fusiforme* in slash pine cotyledons. Plant Dis. Rep. 59:407-410.

Jewell, F.F. and S.L. Mallett.
1964. Resistance to fusiform rust in slash pine as shown by artificial inoculation. Phytopathology 54:1294.

Jewell, F.F. and S.L. Mallett.
1966. Testing slash pine for rust resistance. For. Sci. 13:413-418.

Jewell, F.F. and G.A. Snow.
1972. Anatomical resistance to gall-rust infection in slash pine. Plant Dis. Rep. 56:531-534.

Jewell, F.F. and D.C. Speirs.
1976. Histopathology of one- and two-year-old resisted infections by *Cronartium fusiforme* in slash pine. Phytopathology 66:741-748.

Jewell, F.F., R.P. True, and S.L. Mallett.
1962. Histology of *Cronartium fusiforme* in slash pine seedlings. Phytopathology 52:850-858.

Jewell, F.F. and N.M. Walker.
1967. Histology of *Cronartium quercuum* on shortleaf pine. Phytopathology 57:545-550.

Johnson, H.W. and C.W. Edgerton.
1936. A heart rot of magnolia caused by *Fomes geotropus*. Mycologia 28:292-295.

Kais, A.G.
1964. Germination and growth of *Scirrhia acicola* in liquid culture inhibited by cycloheximide semicarbazone. Plant Dis. Rep. 48:553-556.

Kais, A.G.
1966. Persistance of albinism in *Cronartium fusiforme*. Plant Dis. Rep. 50:842.

Kais, A.G.
1971. Dispersal of *Scirrhia acicola* spores in southern Mississippi. Plant Dis. Rep. 55:309-311.

Kais, A.G.
1975. Environmental factors affecting brown-spot infections on longleaf pine. Phytopathology 65:1389-1392.

Kais, A.G.
1975a. Fungicidal control of *Scirrhia acicola* on longleaf pine seedlings. Plant Dis. Rep. 59:686-688.

Kais, A.G. and G.A. Snow.
1972. Host response of pines to various isolates of *Cronartium quercuum* and *Cronartium fusiforme*. U.S. Dep. Agric. Misc. Publ. 1221:495-503.

Kaufert, F.H.
1933. Fire and decay injury in the southern bottomland hardwoods. J. For. 31:64-67.

Kelley, W.D.
1975. Physiological differences among isolates of *Phytophthora cinnamomi*. Can. J. Microbiol. 21:1548-1552.

Kelley, W.D. and E.A. Curl.
1972. Effect of cultural practices and biotic soil factors on *Fomes annosus*. Phytopathology 62:422-427.

Kelley, W.D. and T.C. Davis, Jr.
1973. Conidiophores and basidiocarps of *Fomes annosus* in east central Alabama. Phytopathology 63:1424.

Kelley, W.D. and R. Rodriguez-Kabana.
1970. Enzymatic activity of *Phytophthora cinnamomi* in sterilized soil. Phytopathology 60:584.

Kelley, W.D. and R. Rodriguez-Kabana.
1975. Sodium azide as a soil fumigant in forest tree nurseries. Proc. Amer. Phytopath. Soc. 2:47.

Kelley, W.D. and R. Rodriguez-Kabana.
1976. Competition between *Phytophthora cinnamomi* and *Trichoderma* spp. in autoclaved soil. Can. J. Microbiol. 28:1120-1127.

Kelman, A. and G.V. Gooding, Jr.
1965. A root and stem rot of yellow-poplar caused by *Cylindrocladium scoparium*. Plant Dis. Rep. 49:797-801.

Kelman, A., C.S. Hodges, Jr., and H.R. Garriss.
1960. Needle blight of redcedar, *Juniperus virginiana*. Plant Dis. Rep. 44:527-531.

Kinloch, B.B., Jr. and A. Kelman.
1965. Relative susceptibility to fusiform rust of progeny lines from rust-infected and non-infected loblolly pine. Plant Dis. Rep. 49:872-874.

Kinloch, B.B., Jr., and R.W. Stonecypher.
1969. Genetic variation in susceptibility to fusiform rust in seedlings from a wild population of loblolly pine. Phytopathology 59:1246-1255.

Kirk, T.K. and A. Kelman.
1965. Lignin degradation as related to the phenoloxidases of selected wood-decaying Basidiomycetes. Phytopathology 55:739-745.

Koenigs, J.W.
1960. *Fomes annosus*: a bibliography with subject index. U.S. Dep. Agric. For. Serv. So. For. Exp. Sta. Occas. Pap. 181,35p.

Koenigs, J.W.
1968. Control of fusiform rust on southern pines in nurseries. Plant Dis. Rep. 52:597-599.

Koenigs, J.W.
1969. Growth and survival of *Fomes annosus* at high concentrations of borax. Phytopathology 59:1717-1721.

Koenigs, J.W.
1970. Inoculation of southern pine seedlings under aseptic conditions. For. Sci. 16:280-286.

Kuhlman, E.G.
1969. Number of conidia necessary for stump root infection by *Fomes annosus*. Phytopathology 59:1168-1169.

Kuhlman, E.G.
1969a. Survival of *Fomes annosus* spores in soil. Phytopathology 59:198-201

Kuhlman, E.G.
1969b. Inoculation of loblolly pine seedlings with *Fomes annosus* in the greenhouse. Can. J. Bot. 47:2079-2082.

Kuhlman, E.G.
1970. Seedling inoculations with *Fomes annosus* show variation in virulence and in host susceptibility. Phytopathology 60:1743-1746.

Kuhlman, E.G.
1973. Variation in infection of loblolly pine roots on high and low hazard sites in the southeastern United States. Proc. Fourth Internal. Conf. on *Fomes annosus*, p 179-183.

Kuhlman, E.G. and F.F. Hendrix, Jr.
1962. A selective medium for the isolation of Fomes annosus. Phytopathology 52:1310-1312.

Kuhlman, E.G., C.S. Hodges, Jr., and R.C. Froelich.
1976. Minimizing losses to Fomes annosus in the southern United States. U.S. Dept. Agric. For. Serv. Res. Pap. SE-151,16p.

Kuhlman, E.G. and E.W. Ross.
1970. Regeneration of pine on Fomes annosus-infected sites in the southeastern United States. Proc. Third Internat. Conf. on Fomes annosus, p71-76.

Levi, M.P.
1973. The durability and treatability of southern pine veneer cores-a preliminary study. Amer. Wood Preservers Assoc. Proc. 69:224-229.

Levi, M.P., D. Huisingh, and W.B. Nesbitt.
1974. Plant uptake of wood preservatives from treated posts not detected. For. Prod. J. 24(9):97-98.

Lightle, P.C. and J.W. Starr.
1957. Heartrot in southern pines. U.S. Dep. Agric. For. Serv. So. For. Notes #108.

Lindgren, R.M.
1951. Deterioration of southern pine pulpwood during storage. Proc. For. Prod. Res. Soc. 5:169-180.

Lindgren, R.M.
1953. Deterioration losses in stored southern pine pulpwood. Tappi 36:260-263.

Lindgren, R.M. and G.M. Harvey.
1952. Decay control and increased permeability in southern pine sprayed with fluoride solutions. J. For. Prod. Res. Soc. 2(5):250-256.

Lohman, M.L., E.K. Cash, and R.W. Davidson.
1942. An unidentified Atropellis on cankered Pinus virginiana. J. Wash. Acad. Sci. 32:296-298.

Long, W.H.
1913. A preliminary note on Polyporus dryadeus as a root parasite on the oak. Phytopathology 3:285-287.

Long, W.H.
1917. Investigations of the rotting of slash in Arkansas. U.S. Dep. Agric. Bull. 496,15p.

Lowe, J.L.
1961. Synopsis of the Polyporaceae of the Southeastern United States. J. Elisha Mitchell Sci. Soc. 77:43-61.

Mann, W.F., Jr., B.C. Williamson, and J.M. McGilvray.
1971. Parasitic weed--A new problem. For. Farmer 30(6):6-8.

Marx, D.H. and W.C. Bryan.
1969. Studies on ectomycorrhizae of pine in an electronically air-filtered airconditioned, plant-growth room. Can. J. Bot. 47:1903-1909.

Marx, D.H., W.C. Bryan, and C.B. Davey.
1970. Influence of temperature on aseptic syntheses of ectomycorrhizae by *Thelephora terrestris* and *Pisolithus tinctorius* on loblolly pine. For. Sci. 16:424-431.

Marx, D.H. and B. Zak.
1965. Effect of pH on mycorrhizal formation of slash pine in aseptic culture. For. Sci. 11:66-75.

Mathews, F.R.
1964. Some aspects of the biology and the control of southern cone rust. J. For. 62:881-884.

Mathews, F.R. and S.J. Rowan.
1972. An improved method for large-scale inoculation of pine and oak with *Cronartium fusiforme*. Plant Dis. Rep. 56:931-934.

May, J.T. and J.F. Goggans.
1950. Southern fusiform rust of slash and loblolly pine in the Alabama Piedmont. Ala. Polytech Inst. Agric. Exp. Sta. Leaflet 30,6p.

McCracken, F.I.
1972. Sporulation of *Pleurotus ostreatus*. Can. J. Bot. 50:2111-2115.

McDaniel, A.T. and C.L. Wilson.
1962. A study of symptoms and control of *Phomopsis juniperovora* on Arizona cypress. Plant Dis. Rep. 46:364-365.

Miles, L.E.
1934. The rusts of Mississippi. Plant Dis. Rep. 18:54-73.

Miller, J.H.
1935. Forest seed bed diseases in Georgia and South Carolina. Plant Dis. Rep. 19:259.

Miller, J.H.
1941. The Ascomycetes of Georgia. Plant Dis. Rep. Suppl. 131:31-93.

Miller, J.H.
1950. A historical sketch of diseases of forest trees in Georgia. Plant Dis. Rep. Suppl. 191:98-101.

Miller, J.H.
1961. A monograph of the world species of Hypoxylon, 158p. U. of Georgia Press.

Miller, J.H. and G. Burton.
1942. Georgia Pyrenomycetes III. Mycologia 34:1-7.

Miller, T.
1970. Inoculation of slash pine seedlings with stored basidiospores of Cronartium fusiforme. Phytopathology 60:1773-1774.

Miller, T.
1972. Fusiform rust in planted slash pines: Influence of site preparation and spacing. For. Sci. 18:70-75.

Miller, T. and A. Kelman.
1966. Growth of Fomes annosus on roots of suppressed and dominant loblolly pines. For. Sci. 12:225-233.

Miller, T. and R.W. Roncardori.
1966. Abjection of secondary sporidia of Cronartium fusiforme. Phytopathology 56:1326-1327.

Myren, D.T. and A. Kelman.
1975. Fungi inhabiting fusiform rust galls and some properties of rust-infected tissue. Plant Dis. Rep. 59:148-151.

Nelson, R.M.
1931. Decay in loblolly pine on the Atlantic Coastal Plain. In: Selective logging in the loblolly pine-hardwood forests of the Middle Atlantic Coastal Plain with special reference to Virginia. Va. For. Serv. Publ. 43:58-59.

Nelson, R.M.
1934. Effect of bluestain fungi on southern pines attacked by bark beetles. Phytopatholog. Zeitschrift 7:327-353.

Nelson, R.M.
1940. Vigorous young yellow-poplar trees can recover from injury by nectria cankers. J. For. 38:587-588.

Nelson, R.M. and G.F. Gravatt.
1929. Tannin content of dead chestnut trees. J. Amer. Leather Chemists Assoc. 24:479-499.

Parris, G.K.
1966. Death of honeylocust in Mississippi associated with Polyporus lucidus. Plant Dis. Rep. 50:243-244.

Parris, G.K.
1967. "Needle curl" of loblolly pine. Plant Dis. Rep. 51:805-806.

Peterson, R.S. and F.F. Jewell.
1968. Status of American stem rusts of pine. Ann. Rev. Phytopath. 6:23-40.

Plakidas, A.G.
1942. Venturia acerina, the perfect stage of Cladosporium humile. Mycologia 24:27-37.

Plakidas, A.G.
1960. Angular leaf spot of magnolia. Mycologia 52:255-259.

Powers, H.R., Jr.
1968. Distance of needle infection from stem affects likelihood of gall development on slash pine by Cronartium fusiforme. Phytopathology 58:1147-1149.

Powers, H.R., Jr.
1969. Testing of pathogenic variability within Cronartium fusiforme and C. quercuum. Proc. UFRO Advanced Study Institute. August 1969 pp. 505-509.

Powers, H.R., Jr.
1971. Variation in shape of rust galls on loblolly pine. Plant Dis. Rep. 55:623-625.

Powers, H.R., Jr.
1972. Comandra rust on southern pines. J. For. 70:18-20.

Powers, H.R., Jr.
1975. Relative susceptibility of five southern pines to Cronartium fusiforme. Plant Dis. Rep. 59:312-314.

Powers, H.R., Jr., J.P. McClure, H.A. Knight, and G.F. Dutrow.
1974. Incidence and financial impact of fusiform rust in the South. J. For. 72:398-401.

Powers, H.R., Jr. and R.W. Roncadori.
1966. Teliospore germination and sporidial production by Cronartium fusiforme. Plant Dis. Rep. 50:432-434.

Powers, H.R., Jr. and W.A. Stegall, Jr.
1965. An evaluation of cycloheximide (Acti-Dione) for control of white pine blister rust in the southeast. Plant Dis. Rep. 49:342-346.

Powers, H.R., Jr. and A.F. Verrall.
1962. A closer look at Fomes annosus. For. Farmer 21(13) 8-9, 16-17.

Rockwood, D.L. and R.E. Goddard.
1973. Predicting gains for fusiform rust resistance in slash pine. Proc. 12th South. For. Tree Improve. Conf. p31-37.

Roncadori, R.W.
1968. The pathogenicity of secondary and tertiary basidiospores of Cronartium fusiforme. Phytopathology 58:712-713.

Roncadori, R.W. and F.R. Mathews.
1966. Storage and germination of aeciospores of Cronartium fusiforme. Phytopathology 56:1328-1329.

Ross, E.R.
1969. Thermal inactivation of conidia and basidiospores of Fomes annosus. Phytopathology 59:1798-1801.

Ross, E.W.
1973. Fomes annosus in the southeastern United States: Relation of environmental and biotic factors to stump colonization and losses in the residual stand. U.S. Dep. Agric. Tech. Bull. 1459,26p.

Ross, E.W. and C.S. Hodges.
1964. Fomes annosus infections in young slash pine plantations. Phytopathology 54:904 (abst.).

Ross, E.W. and D. H. Marx.
1972. Susceptibility of sand pine to Phytophthora cinnamomi. Phytopathology 62:1197-1200.

Roth, E.R.
1941. Top rot in snow damaged yellow poplar and basswood. J. For. 39:60-62.

Roth, E.R.
1943. Effect of invisible decay on deterioration of untreated oak ties and posts. J. For. 41:117-121.

Roth, E.R.
1948. Healing and defects following oak pruning. J. For. 46:500-504.

Roth, E.R.
1950. Discolorations in living yellow-poplar trees. J. For. 48:184-185.

Roth, E.R.
1951. The viability of spores and mycelium of *Endoconidiophora virescens* on sugar maple lumber. Plant Dis. Rep. 35:379-381.

Roth, E.R.
1952. Roots of living *Pinus rigida* decayed by *Fomes annosus*. Plant Dis. Rep. 36:330.

Roth, E.R.
1956. Decay following thinning of sprout oak clumps. J. For. 54:26-30.

Roth, E.R. and C. Hartley.
1957. Decay prevention in wooden boats during storage. U.S. Dep. Agric. For. Serv. Report SR-12401, 46p.

Roth, E.R. and G.H. Hepting.
1943. Wounds and decay caused by removing large companion sprouts of oak. J. For. 41:190-195.

Roth, E.R. and G.H. Hepting.
1943a. Origin and development of oak stump sprouts as affecting their likelihood to decay. J. For. 41:27-36.

Roth, E.R. and G.H. Hepting.
1943b. Wounds and decay caused by removing companion sprouts of oak. J. For. 41:190-195.

Roth, E.R. and G.H. Hepting.
1946. Pitch canker, a new disease of some southern pines. J. For. 44:742-744.

Roth, E.R. and G.H. Hepting.
1954. Eradication and thinning tests for Nectria and Strumella canker control in Maryland. J. For. 52:253-256.

Roth, E.R., E.R. Toole, and G.H. Hepting.
1948. Nutritional aspects of the littleleaf disease of pine. J. For. 46:578-587.

Ruehle, J.L.
1962. Histopathological studies of pine roots infected with lance and pine cystoid nematodes. Phytopathology 52:68-71.

Ruehle, J.L.
1964. Plant-parasitic nematodes associated with pine species in southern forests. Plant Dis. Rep. 48:60-61.

Ruehle, J.L.
1973. Nematodes and forest trees-types of damage to tree roots. Ann. Rev. Phytopath. 11:99-118.

Ruehle, J.L. and J.N. Sasser.
1962. The role of plant-parasitic nematodes in stunting of pine in southern plantations. Phytopathology 52:56-68.

Ruehle, J.L. and J.N. Sasser.
1964. Additional data on results of nematicidal fumigation in pine plots in North Carolina. Plant Disease Rep. 48:534-536.

Scheffer, T.C. and R.M. Lindgren.
1940. Stains of sapwood and sapwood products and their control. U.S. Dep. Agric. Tech. Bull. 714,124p.

Scheffer, T.C., A.F. Verrall, and G.M. Harvey.
1963. On-site preservative treatments: Their effectiveness for exterior millwork of different species used in various climates. For. Prod. J. 13(1):7-13.

Scheffer, T.C., A.F. Verrall, and G. Harvey.
1971. Fifteen-year appraisal of dip treating for protecting exterior woodwork: Effectiveness on different wood species and in various climates. Material und Organismen 6:27-44.

Scheffer, T.C. and A.F. Verrall.
1973. Principles for protecting wood buildings from decay. U.S. Dep. Agric. For Serv. Res. Pap. FPL-190,55p.

Scheld, H.W. and R.C. DeGroot.
1971. Toughness of sapwood in water-sprayed longleaf pine logs. For. Prod. J. 21(4):33-34.

Scheld, H.W., Jr., and A. Kelman.
1963. Influence of environmental factors on *Phomopsis juniperovora*. Plant Dis. Rep. 47:932-935.

Schmidt, R.A.
1972. A literature review of inoculation techniques used in studies of fusiform rust. NATO-IUFRO Advanced Study Institute. U.S. Dep. Agric. For. Serv. Misc. Pub. 1221, p341-356.

Schmidt, R.A. and R.E. Goddard.
1971. Preliminary results of fusiform rust resistance from field progeny tests of selected slash pine. Proc. Eleventh Conf. South. For. Tree Improve. p.37-44.

Schmidt, R.A., R.E. Goddard, and C.A. Hollis.
1974. Incidence and distribution of fusiform rust in slash pine plantations in Florida and Georgia. Univ. Fla. IFAS Agric. Exp. Sta. Bull. 763,21p.

Schmidt, R.A., M.J. Foxe, C.A. Hollis, and W.H. Smith.
1972. Effect of N,P, and K on the incidence of fusiform rust galls on greenhouse-grown seedlings of slash pine. Phytopathology 62:788 (abst.)

Schmidt, R.A. and C.P. Seymour.
1972. Etiology of oak decline in Florida ferneries. Plant Dis. Rep. 56:811-814.

Schmidt, R.A. and E.M. Underhill.
1974. Incidence and impact of pitch canker in slash pine plantations in Florida. Plant Dis. Rep. 58:451-454.

Shain, L.
1967. Resistance of sapwood in stems of loblolly pine to infection by _Fomes annosus_. Phytopathology 57:1034-1045.

Shoulders, E., J.P. Hollis, R.G. Merrifield, E.E. Turner, and A.F. Verrall
1965. Test of soil fumigants in Louisiana. Tree Planters Notes No. 73(Oct):14-21.

Siggers, P.V.
1935. Slash-disposal methods in logging shortleaf pine. U.S. Dep. Agric. For. Serv. So. Sta. Occasional Pap. 42,5p.

Siggers, P.V.
1944. The brown spot needle blight of pine seedlings. U.S. Dep. Agric. Tech. Bull. 870,36p.

Siggers, P.V.
1950. Possible mechanism of variation in the imperfect stage of _Scirrhia acicola_. Phytopathology 40:726-728.

Siggers, P.V.
1955. Control of the fusiform rust of southern pines. J. For. 53:442-446.

Siggers, P.V. and K.D. Doak.
1940. The littleleaf disease of shortleaf pine. U.S. Dep. Agric. For. Serv. So. For. Exp. Sta. Occas. Pap. 95,5p.

Smalley, G.W. and R.L. Sheer.
1963. Blackroot rot in Florida sand hills. Plant Dis. Rep. 47:669-671.

Snow, G.A.
1961. Artificial inoculation of longleaf pine with *Scirrhia acicola*. Phytopathology 51:186-188.

Snow, G.A., F.J. Czabator, and S.S. Sorrels.
1964. Cycloheximide derivatives for controlling brown spot on longleaf pine. Plant Dis. Rep. 48:551-556.

Snow, G.A., R.J. Dinus, and A.G. Kais.
1975. Variation in pathogenicity of diverse sources of *Cronartium fusiforme* on selected pine families. Phytopathology 65:170-175.

Snow, G.A., R.J. Dinus, and C.H. Walkinshaw.
1976. Increase in virulence of *Cronartium fusiforme* on resistant slash pine. Phytopathology 66:511-513.

Snow, G.A., F.F. Jewell, and L.N. Eleuterius.
1963. Apparent recovery of slash and loblolly pine seedlings from fusiform rust infection. Plant Dis. Rep. 47:318-319.

Snow, G.A. and A.G. Kais.
1972. Technique for inoculating pine seedlings with *Cronartium fusiforme*. In Biology of rust resistance in forest trees. U.S. Dept. Agric. For. Serv. Misc. Publ. 1221 pp325-326.

Snyder, E.B. and H.J. Derr.
1972. Breeding longleaf pines for resistance to brown spot needle blight. Phytopathology 62:325-327.

Snyder, W.C., E.R. Toole, and G.H. Hepting.
1949. *Fusaria* associated with mimosa wilt, sumac wilt, and pine pitch canker. J. Agric. Res. 78:365-382.

Sohn, S.T., R.E. Goddard, and R.A. Schmidt.
1975. Comparative performances of slash pine for fusiform rust resistance in high rust hazard locations. Proc. 13th South. For. Tree Improve. Conf. p.204.

Stambaugh, W.J., F.W. Cobb, R.A. Schmidt, and F.C. Krieger.
1962. Seasonal inoculum dispersal and white pine stump invasion by Fomes annosus. Plant Dis. Rep. 46:194-198.

Stonecypher, R.W., B.J. Zobel, and R.L. Blair.
1973. Inheritance patterns of loblolly pines from a non-selected natural population. N.C. Agric. Exp. Sta. Bull. 220,60p.

Tainter, F.H.
1971. Rust disease threatens Arkansas forests. Ark. Farm Res. 20(2):9.

Tainter, F.H.
1972. Oak wilt, a selective silvicide in Arkansas? Ark. Farm Res. 21(6):8.

Tainter, F.H.
1973. Development of Cronartium camandrae in Comandra umbellata. Can. J. Bot. 51:1369-1372.

Tainter, F.H. and W.D. Gubler.
1973. Natural biological control of oak wilt in Arkansas. Phytopathology 63:1027-1034.

Tainter, F.H. and W.D. Gubler.
1974. Effect of Hypoxylon and other microorganisms on carbohydrate reserves of oak-wilted trees. For. Sci. 20:337-342.

Tainter, F.H., M. Tucker, B. Washburn, and J. Tiner.
1974. Oak wilt remains static in Arkansas. Plant Dis. Rep. 58:622-624.

Taylor, W.K. and J.S. Boyce, Jr.
1965. Effect of phytoactin on the fusiform rust fungus, Cronartium fusiforme. Plant Dis. Rep. 49:698-701.

Thompson, J.N., E.B. Cowling, and E.W. Ross.
1962. Changes in moisture content and color of the cambial zone of bolts of pine sapwood during colonization by Fomes annosus. Can. J. Bot. 46:1533-1537.

Toole, E.R.
1941. Fusarium wilt of the mimosa tree (Albizzia julibrissin). Phytopathology 31:599-616.

Toole, E.R.
1949. Fusarium wilt of staghorn sumac. Phytopathology 39:754-759.

Toole, E.R.
1949a. White pine blight in the Southeast. J. For. 47:378-382.

Toole, E.R.
1959. Decay after fire injury to southern bottomland hardwoods. U.S. Dept. Agric. Tech. Bull. 1189,25p.

Toole, E.R.
1961. Rot entrance through dead branches in southern hardwoods. For. Sci. 7:218-226.

Toole, E.R.
1963. Sweetgum lesion caused by Botryosphaeria ribis. Plant Dis. Rep. 47:229-231.

Toole, E.R.
1964. Progress of oak heartrot varies with height in tree. Plant Dis. Rep. 48:585.

Toole, E.R.
1965. Decay 10 years after thinning of sweetgum sprout clumps. Plant Dis. Rep. 49:986.

Toole, E.R.
1965a. Deterioration of hardwood logging slash in the South. U.S. Dep. Agric. Tech. Bull. 1328,27p.

Toole, E.R.
1970. Variation in decay resistance of southern pine sapwood. For. Prod. J. 20(5):49-50.

Toole, E.R.
1971. Influence of season on organisms infecting untreated southern pine stakes. Phytopathology 61:1013-1014.

Toole, E.R.
1971a. Evaluation of wood preservatives using crushing strength. Phytopathology 61:182-183.

Toole, E.R.
1971b. Germination of spores of wood decay fungi on wood. Phytopathology 61:88-90.

Toole, E.R.
1971c. Reduction in crushing strength and weight associated with decay by rot fungi. Wood Sci. 3(3):172-178.

Toole, E.R.
1972. Effect of decay fungi on the microstructure of red oak heartwood. Wood Sci. 5:34-37.

Toole, E.R.
1975. Oxygen utilization by decay fungi for the evaluation of wood preservatives. For. Prod. J. 25(7):46-48.

Toole, E.R. and M.M. Barnes.
1974. Biodeterioration of particle board. For. Prod. J. 24(10):55-57.

Toole, E.R. and W.M. Broadfoot.
1959. Sweetgum blight as related to alluvial soils of the Mississippi River flood plain. For. Sci. 5:2-9.

Toole, E.R. and W.M. Broadfoot.
1959a. Irrigation lessens sweetgum blight. U.S. Dept. Agric. For. Serv. South For. Notes 120.

Toole, E.R. and W.N. Darwin.
1970. Influence of variation in physical and chemical properties of red oak lumber on decay resistance. Miss. Sta. Univ. For. Prod. Util. Lab. Res. Rep. 10,8p.

Toole, E.R. and J.L. Gammage.
1959. Damage from increment borings in bottomland hardwoods. J. For. 57:909-916.

Toole, E.R. and G.H. Hepting.
1949. Selection and propagation of Albizzia for resistance to Fusarium wilt. Phytopathology 39:63-70.

Toole, E.R. and P.C. Lightle.
1960. Status of persimmon wilt. Plant Dis. Rep. 44:45.

Towers, B. and W.J. Stambaugh.
1968. The influence of induced soil moisture stress upon Fomes annosus root rot of loblolly pine. Phytopathology 58:269-272.

True, R.P.
1946. Some fungi are agents of dry-face. AT-FA J. 8(8):11-14,20.

True, R.P. and R.D. McCulley.
1945. Defects above naval stores faces. South. Lumberman 171(2153):200, 202, 204.

True, R.P. and M.M. Smucker.
1947. Symptoms induced at standard wounds by fungi isolated from dry turpentine faces. Phytopathology 37:437 (abst.).

Van Arsdel, E.P. and D.L. Bush.
1970. The remote sensing of oak-decline symptoms. Phytopathology 60:589 (abst.).

Van Arsdel, E.P. and A. Chitzonidis.
1970. Life cycle and spread of ash rust in Texas. Phytopathology 60:1317 (abst.).

Van Arsdel, E.P. and R.S. Halliwell.
1970. Progress in research on live oak decline. Plant Dis. Rep. 54:669-674.

Van Arsdel, E.P., S.D. Lyda, and T.W. Jares.
1972. Treatment of *Cephalosporium* wilt disease with a benomyl fungicide. Phytopathology 62:807 (abst.).

Veal, M.A., R.L. Blair, J.B. Jett, W.T. McKean, and E.B. Cowling.
1974. Impact of fusiform rust on pulping properties of young loblolly pine. Proc. 1974 Ann. Meet. Amer. Phytopath. Soc. Abst. 185.

Veech, J.A. and J.S. Boyce, Jr.
1964. Soil microorganisms in two Georgia slash pine plantations with annosus root rot. Plant Dis. Rep. 48:873-874.

Verrall, A.F.
1934. The resistance of saplings and certain seedlings of *Pinus palustris* to *Septoria acicola*. Phytopathology 24:1262-1264.

Verrall, A.F.
1936. The dissemination of *Septoria acicola* and the effect of grass fires on it in pine needles. Phytopathology 26:1021-1024.

Verrall, A.F.
1939. Relative importance and seasonal prevalence of wood-staining fungi in the southern states. Phytopathology 29:1031-1051.

Verrall, A.F.
1941. Dissemination of fungi that stain logs and lumber. J. Agric. Rec. 63:549-558.

Verrall, A.F.
1941a. Fungi associated with stain in chemically treated green lumber. Phytopathology 31:270-274.

Verrall, A.F.
1942. A comparison of *Diplodia natalensis* from stained wood and other sources. Phytopathology 32:879-884.

Verrall, A.F.
1943. Fungi associated with certain ambrosia beetles. J. Agric. Res. 66:135-144.

Verrall, A.F.
1949. Some molds on wood favored by certain toxicants. J. Agric. Res. 78:695-703.

Verrall, A.F.
1961. Spread of Cronartium fusiforme branch infections. Phytopathology 51:646 (abst.).

Verrall, A.F.
1962. Condensation in air-cooled buildings. For. Prod. J. 12:531-536.

Verrall, A.F.
1965. Preserving wood by brush, dip, and short-soak methods. U.S. Dep. Agric. Tech. Bull. 1334,50p.

Verrall, A.F.
1966. Building decay associated with rain seepage. U.S. Dep. Agric. Tech. Bull. 1366,58p.

Verrall, A.F.
1968. Poria incrassata rot: Prevention and control in buildings. U.S. Dep. Agric. Tech. Bull. 1385,27p.

Verrall, A.F.
1968a. A possibly new pine-oak rust. Plant Dis. Rep. 52:248.

Verrall, A.F.
1970. Log storage under water spray makes lumber more porous. Stephen F. Austin Sta. Univ. Texas Forestry Paper 1,4p.

Verrall, A.F. and T.L. Amburgey.
1979. Prevention and control of decay in homes. Unnumbered, undated bulletin of U.S. Govt. Printing Office, 148p.

Verrall, A.F. and P.V. Mook.
1951. Research on chemical control of fungi in green lumber, 1940-1951. U.S. Dep. Agric. Tech. Bull. 1046,60p.

Verrall, A.F. and T.C. Scheffer.
1959. Preservative treatments for protecting wood boxes. U.S. Dep. Agric. For. Serv. Res. Pap. FPL-106,57p.

Verrall, A.F., E.R. Toole, and P.C. Lightle.
1959. Oak wilt in Oklahoma and Arkansas. Plant Dis. Rep. 43:1288.

Von Weissenberg, K.
1973. Indirect selection for resistance to fusiform rust. Acta Forestalia Finnica 134:1-46.

Wakeley, P.C.
1968. Rust susceptibility in longleaf pine associated with brown-spot resistance and early commencement of height growth. For. Sci. 14:323-324.

Wakeley, P.C.
1970. Thirty-year effects of uncontrolled brown spot on planted longleaf pine. For. Sci. 16:197-202.

Walkinshaw, C.H.
1965. Chemical inhibition in germination of Cronartium fusiforme aeciospores. Phytopathology 55:996-999.

Weber, G.F.
1930. Dry rot of lumber in storage and in buildings. Fla. Agric. Exp. Sta. Press Bull. 424,2p.

Wells, O.O. and G.L. Switzer.
1971. Variation in rust resistance in Mississippi loblolly pine. Proc. 11th. Conference on Southern Forest Tree Improvement:25-30.

Wilson, C.L.
1959. Chlorosis of loblolly and shortleaf pine seedlings related to calcium content of nursery soil. Plant Disease Rep. 43:964-965.

Wilson, C.L.
1961. Study of the growth of Ceratocystis fagacearum in oak wood with the use of autoradiograms. Phytopathology 51:210-215.

Wilson, C.L.
1961a. An undescribed blight of Arizona cypress. Plant Dis. Rep. 45:96-98.

Wilson, C.L.
1963. Wilting of persimmon caused by Cephalosporium diospyri. Phytopathology 53:1402-1406.

Wilson, C.L.
1965. Consideration of the use of persimmon wilt as a silvicide for weed persimmon. Plant Dis. Rep. 49:789-791.

Wilson, C.L.
1965a. Ceratocystis ulmi in elm wood. Phytopathology 55:477.

Witcher, W.
1963. Spread of Fomes annosus in a certain pine stand. S.C. Acad. Sci. 25:23.

Witcher, W., J.D. Amett, L.W. Baxter, and M.L. Cocke.
1975. Control of needle cast of Scotch pine in South Carolina. Plant Dis. Rep. 59:881-883.

Witcher, W., L.W. Baxter, and S.A. Marbut.
1973. Benomyl promising chemical for leaf and stem diseases of redcedar and Arizona cypress. Plant Dis. Rep. 57:315-317.

Witcher, W. and R.E. Beach.
1962. Fomes annosus infection through pruned branches of slash pine. Plant Dis. Rep. 46:64.

Wolf, F.A. and J. Barbour.
1941. Brown-spot needle disease of pines. Phytopathology 31:61-74.

Wolf, F.A., K.H. Garren, and J.K. Miller.
1938. Fungi of the Duke Forest. Duke Univ. School For. Bull. 2,122p.

Wolf, F.A. and F.T. Wolf.
1939. A study of Botryosphaeria ribis on willow. Mycologia 31:217-227.

Zak, B. and W.C. Bryan.
1963. Isolation of fungal symbionts from pine mycorrhizae. For. Sci. 9:270-278.

Zak, B. and D.H. Marx.
1964. Isolation of mycorrhizal fungi from roots of individual slash pines. For. Sci. 10:214-222.

Zobel, B.J., R.L. Blair, and M. Zoerb.
1971. Using research data--Disease resistance. J. For. 69:486-489.

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VERRALL, ARTHUR F.

1982. A history of forest pathology in the South and Southeast, U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. SO-36,200 p. South. For. Exp. Stn. New Orleans, La.

This history brings together the literature and the lives of those connected with forest disease research in the South and the Southeast. The author presents the "why" aspects along with the "what" of such research.

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Proceedings

of the

SOUTHERN CONTAINERIZED FOREST TREE SEEDLING CONFERENCE

Edited by

Richard W. Guldin and James P. Barnett

Savannah, Georgia

August 25-27, 1981

Sponsored by:

- Southern Forest Experiment Station
- Southeastern Forest Experiment Station
- Southeastern Area State and Private Forestry
- Silvicultural Working Group, Society of American Foresters
- Georgia Cooperative Extension Service
- Georgia Pacific Corporation

PREFACE

Research findings provide benefits to society when they are communicated to and implemented by us This principle was the rationale for the Southern Containerized Forest Tree Seedling Conference. In t 8 years since the North American Containerized Forest Tree Seedling Symposium in August 1974, souther esters have developed container seedling nurseries and begun large-scale planting programs. By their perience and research, the state-of-the-art has been rapidly advanced. It was time to redefine the st of-the-art for the 1980s.

The conference objective was to describe and discuss the state-of-the-art of growing and plantin tainerized tree seedlings for reforestation in the South. The program developed alternative approache examined the potential for expanding the use of this regeneration method.

Many individuals and organizations deserve credit for the success of the conference. Each of ou speakers did a fine job of covering his assigned topic. We are especially grateful for the presentati of those nurserymen who shared their trials in developing large-scale nurseries and field planting pr so their successors need not repeat their errors. They have added more to the font of knowledge than realize and serve as witnesses that planting containerized seedlings is a viable reforestation method moderators proved adept at keeping the sessions on schedule, providing insights of their own, and lea the informative discussion periods. The speakers are responsible for the content of their papers and mitted them in camera-ready form.

In addition to our speakers, 4 individuals merit special mention for their contributions to confe planning and arrangements:

John C. Brissette, Southeastern Area State and Private Forestry,
U.S. Forest Service, Jackson, Mississippi

William E. Balmer (Ret.), Southeastern Area State and Private Forestry,
U.S. Forest Service, Atlanta, Georgia

David C. Borem, Georgia-Pacific Corporation, Savannah, Georgia

H. Lamar Merck, Georgia Cooperative Extension Service,
Statesboro, Georgia.

Finally, we acknowledge the support of the Silvicultural Working Group of the Society of America esters and the exhibitors. The SAF Continuing Forestry Education and Professional Development Progra awarded 16.5 hours of Category 1 credit to each conference attendee.

The South's Third Forest report, published by the Southern Forest Resource Analysis Committee in stated that developing "year-long planting and seeding schedules for principal forest species" was on the most important forest research needs to assure adequate future wood supplies. We feel that the au have made a large contribution toward meeting that need. Through this volume, we transfer a new regen tion technology to you, the reader, hoping that society will be the ultimate beneficiary.

Richard W. Guldin and James P. Barnett
Program Cochairmen

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WELCOME[1]

Robert D. Raisch[2]

Good morning! On behalf of the U. S. Forest Sevice, welcome to the Southern Containerized Foest Tree Seedling Conference. We're pleased to see the diversity of background and interests reresented here today! While most of you are frm private industry and public agencies here in the South, we do have visitors from the West, Caada and even as far away as Sweden. This coference offers a tremendous opportunity to exhange information; informally as well as in th formal sessions. I hope you'll take full adantage of this time together.

The objectives of this conference are: to decribe and discuss the state-of-the-art in prducing and planting containerized tree seedligs; to develop alternative approaches; and to examine the potential use of this regeneration mehod for reforestation in the South! We have an exciting program and well qualified speakers to address the subject matter. However, your paticipation in sharing information and ideas ar essential to insure the maximum benefit from ths conference. These three days and the results of the meeting will be what you make it!

Now to join me in this welcome, it is my privilege to introduce a gentleman from our host state! Under his leadership, as State Forester, the Georgia Forestry Commission started one of the first State Tree Improvement Programs and established one of the first seed orchards in the South.

Georgia has consistently been among the top three states in the country in terms of the number of seedlings produced, the number of acres planted, and the number of genetically improved seedlings produced. It is fitting, then, that we meet here in Georgia!

It is a real personal pleasure to introduce my good friend - State Forester Ray Shirley.

---

[1] Presented at Southern Containerized Forest Tre Seedling Conference, Savannah, Georgia, Auust 25-27, 1981.

[2] Area Director, State and Private Forestry, U.S. Forest Service, Atlanta, Georgia 30367.

REFORESTATION: KEY TO SOUTHERN FOREST PRODUCTIVITY[1]

John C. Barber[2]

Ladies and Gentlemen: Greetings! And another welcome to this conference! I am delighted to be here as your keynote speaker and equally delighted that the Society of American Foresters is one of the sponsors of this conference. Such sponsorship and support is one of the many ways that professional societies can help spread new knowledge quickly and get new technology on the ground promptly. Production and use of containerized seedlings is one of the booming frontiers of forest science and technology. We have moved past the pilot test phase and into large-scale operations. But the technology is still relatively new. Some of it is still uncertain in its results, because there has not been time to fully test, debug, and refine all the processes.

To help put containerization in its proper perspective, let's look back at conventional nurseries. Even after many decades of outdoor nursery management, we still see problems. Ask any nurseryman; you can turn your back for a day and return to find that something has arisen to affect both quantity and quality of the stock. Some of us were around when nurseries were trying to gear up for the Soil Bank. The strain and pain of providing 100 million seedlings for Georgia landowners in one year will be long remembered by those involved. That demand, though, provided a much needed stimulus to seed and nursery research. The modern seed testing and research laboratory that serves you well today at Macon was a direct result of those nursery needs.

And where was containerized planting stock then? As a practical means of establishing forest stands it did not exist. Twenty-five years ago when foresters of the Georgia Foresty Commission were establishing seed orchards, they were grafting on containerized stock. The container was a metal or tarpaper pot that bare-rooted seedlings were planted in to produce grafting stock. It was several years later before many people began to look at the idea of producing seedlings in small containers for plantation establishment on a routine basis.

Soil Bank reforestation was relatively easy. The plantations went on abandoned cropland, just where most of the artificial regeneration and much of the natural pine regeneration in the South had taken place for several decades. But when that former crop and pasture land had been planted, reforestation in the South took on a new identity--an identity of expensive stand conversion from usually worthless brush and hardwood to pine. At best, some form of site preparation after harvest was needed to insure success for a new stand. For all practical purposes, the South no longer has abandoned agricultural land that is available for conversion to forest stands. And though we may prepare forest sites very intensively, the planting and growing conditions are different, and the challenge is more complex.

Soil Bank plantations and subsequently established stands are an important part of southern forest productivity, but you have all heard the predictions of supply and demand for forest products and how the South will be expected to supply increasing quantities of timber to meet national and world needs. It takes only a quick glance at the figures to see why the nation will be turning to the South. Of the roughly 347 million acres of privately owned commercial timberland in the United States, about 170 million is in the South. That consists of slightly less than one-half of the nation's farm and miscellaneous private ownerships and slightly over one-half of the industrial forest land. The public lands in the South are of substantially less regional importance, though they may be quite significant locally.

It is generally agreed that we cannot expect any substantial increases of timber production from public lands in the next several decades, and even on the industrial lands of the South another decade will pass before the substantial investments in site preparation and tree improvement will begin to pay off with wood from high-yielding plantations Thus as demand for wood and fiber rises we can expect additional pressures to fall on the nonindustrial private lands for harvests to meet those demands.

Another facet of the supply problem will be the decreasing acreage in timber production across the South. Two factors are of great significance. First is the pressure for conversion of forest land to agricultural uses. World food needs will continue to rise and will stimulate U.S. production with the consequent demand for increased acreages in crops. Second, the recent National Agricultural Lands Study makes clear that the South will continue to lose substantial acreages of prime agricultural and forest land to urban development, transportation corridors, and other uses. Shifts of America's population to the sun belt and residentia shifts from urban areas to small towns will have their impact. "People" sprawl will usurp and fragment formerly operable agricultural and forest ownerships and will diminish the availability of timber for harvest.

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[1] Paper presented at Southern Containerized Forest Tree Seedling Conference, Savannah, Georgia, August 25-27, 1981.

[2] Executive Vice President, Society of American Foresters.

The National Agricultural Lands Study also identifies the South as the region where there are 20.6 million acres of forest land and 26.6 million of pasture land with medium to high potential for conversion to crops. You can be assured that when some of those millions of acres of pasture are converted to crops they will be replaced from our forest land base. The competition for southern land will be food and textile fiber versus lumber and paper. You must also keep in mind that those conversions to crop and pasture will be the most productive forest sites.

So the result of all of this will be that our increased timber supply must come from a reduced land base. In short, we must increase output per acre to offset the loss of forest land to other uses and to meet increasing needs.

There is no question that the opportunity to increase forest productivity lies with the nonindustrial private forest owner. He--or she--must first place existing stands under good management, and second, regenerate harvested areas to assure the establishment of productive stands of desired species. The major deterrent seems to be the unwillingness of landowners to make long-term investments. This reluctance means that we are not only failing to manage the stands we already have but, more importantly, are failing to regenerate after harvests.

South Georgia is an example of what's happening all over the South. Steve Boyce and Herb Knight of the Southeastern Station looked at the 1962 and 1972 Forest Survey plots here in south Georgia to see what happened after pine stands were harvested. This was an area with some of the highest stumpage prices in the South. The financial incentive should have existed, but it didn't get landowners interested in timber growing. What Boyce and Knight reported was that of the pine stands harvested only 11% were replanted, and 21% were naturally regenerated, but 68% had reverted to hardwoods. And in later surveys a similar lack of response has been found in Virginia, South Carolina, Florida, Mississippi--more or less all over the South. This information points up an observation that has been made a number of times, that is, high stumpage prices are an incentive for the owner to sell timber but they have little effect on investments in regeneration and management. Recent income tax provisions such as the investment tax credit, changes in capital gain rates, and estate tax revisions are all to the good. But with the high cost of money, the biggest help to be added to all of those will be guaranteed results at reduced costs.

That brings us to containerized seedlings as one of the answers to the problem. There is no panacea for the regeneration of forest stands; there is no simple prescription. Each case must be taken on an individual basis; the regeneration system and the subsequent silviculture must be geared to the site and its productive potential, and of course to the landowner's objectives. Any regeneration system must make both biological and economic sense. It must be efficient not only in terms of cost, but in terms of establishment time. The need for effective reforestation with desired species in the South, primarily softwoods, has clearly stated. Many of the needed biological and systems are known, but the financial resou to do the job have not been identified.

On the biological side, our prescription look at site conditions in detail so that we ca tailor the production of nursery stock, the pla ing method and the schedule of planting to mee owner objectives, and assure the establishment healthy and vigorous stand. There has to be qua control throughout the process from the collect of seed until the planted seedling is free to Successful plantations and improved performanc hinge on quality control.

Fulfilling the biological needs of regene systems offers many opportunities for us to ta advantage of the potential of containerized pla stock. The overall opportunity is that of matc the silviculture with the owner's objectives. have the opportunity to choose the best species source to meet management objectives and to giv the highest yields with minimal risks. We have opportunity to plant genetically improved stock can utilize the full productivity of the site. quality control to insure survival, we can guar stocking at the spacing that will favor optimum growth and financial returns. These are opport in the broad sense.

Still other opportunities may exist with containerized seedlings. We hear a great deal the economies of scale, but let's face it, we w be having an increasing number of small operati because of ownership fragmentation and the unwi ingness of owners to harvest more than a small at a time. Containerized stock may improve the economics of small-scale operation because it u lessens the investment necessary for site prepa and planting.

Production and use of containerized stock gives us flexibility to respond to major change planting programs. For example, after a major fire it would be too late to schedule an extra million of bare-root stock, but there might be enough to add the million for late-season produ in a containerized operation. There is also th capability to extend regular planting seasons, in some special cases to plant during the growi season.

Probably some of the greatest opportunitie will be on the difficult sites, those which are potentially productive but have special regener problems such as droughty surface soils, exposed areas, muck soils, competing vegetation, and da from fire, logging, and surface mining.

I look forward to the time when we will hav fully mechanized planting operation where block containerized stock will be fed into a machine automatically inserts them into the soil. And so while traveling over rough sites cluttered wi logging slash and other obstructions that preve the use of any sort of furrow-type machines.

Seven years ago tomorrow a North American Containerized Forest Tree Seedling Symposium co

Denver, Colorado. It was sponsored by the estry Committee of the Great Plains Agricultural ncil and many others, including the USDA Forest vice, the Canadian Forestry Service, and the iety of American Foresters. It was an interional conference to summarize the state of the . Some of the forest scientists who contributed that symposium are here. Again, they will be senting their research results and experiences. will be interesting to learn the progress that's n made in seven years. I know that as they have lected on their 1974 papers and the ensuing cussion in preparation for this conference, y have become acutely aware of the progress e and perhaps even more aware of the problems t still confront us.

Tomorrow we'll see containerized seedling duction in operation. We'll see how the process working and how successful it is thought to be. will judge for yourselves where the South nds in the ability to grow containerized seedgs and to establish them on forest sites. Those you from outside southeast Georgia will wonder things compare with progress back home and ther new ideas on reforestation will work.

I can assure you that when this conference ses Thursday evening, you will at least have n exposed to the state of the art and the avenues research and opportunity that lie ahead. When go home, don't put that new knowledge and those as on the bookshelves of your mind. Don't wait the *Proceedings* even though they'll be availe in a few months. Do think how you as a fessional forest manager, or research scientist, nursery manager can take what you learn here use it to hasten the regeneration of southern ests. Do look at these three days of ideas information exchange as ways of helping meet ure demands of our American society.

Reforestation is the key to southern forest ductivity. Our most valued softwood species, even some desired hardwoods, cannot compete h the lesser valued hardwoods and brush to ablish themselves in highly productive stands. must learn how to follow each timber harvest h adequate regeneration of desired species at per stocking to assure the future timber supply this nation. Containerized seedling production planting systems will be one of the critical ments of our future forest productivity in the th.

A HISTORICAL OVERVIEW OF THE USE OF CONTAINERIZED SEEDLINGS FOR OPERATIONAL REFORESTATION. - HOW DID WE GET WHERE WE ARE TODAY?[1]

Philip F. Hahn[2]

Abstract. --A historical review discusses the various container types, their development, their use, and some of their advantages and disadvantages. A brief description is also given on the reasons for containerization and on how we got in this field and to where we are today.

INTRODUCTION

It was about twenty years ago when I first erd about the potential for the commerical use f containerized seedlings in the area of reforest-ton. The speaker at an Artificial Regneration hrt Course spoke very enthusiastically about the at performance of experimentally tested seed-igs, and strongly advocated the large scale use f such seedlings. However, at that time even the pimists of containerization couldn't visualize adling millions of seedlings in a nursery and in h field, from an economic and logistic point of iw.

Nevertheless, even though it was hard for h optimists to see the application of container-ztion in a practical sense, they held onto the ram and didn't give up. Their drive for con-taerization was aided by the increased demand o reforestation during the 1950's and 60's. ot European countries and parts of the United ttes had a good number of well-developed bare-ot nurseries. But areas like the Pacific North-et and most of Canada were poorly equipped with uh facilities. Consequently, the need for an ncreased amount of seedlings could not be met y the available bareroot nurseries.

In order to fill the immediate needs demand-ed for artificial reforestation in some areas at ht time, the method of aerial seeding was in-rduced and used on a large scale basis. Heli-oters equipped with seed disseminating devices were able to manuever themselves quite rapidly even over the roughest terrain while doing a reasonably good job in distributing the seed on the cut-over areas.

Aerial seeding met an immediate need and is still very useful in some areas. However, it is not able to keep up with the new demands of reforestation in a modern forest management program. To further elaborate on this, a drastic change in land management brought on mostly by the increasing timber values during the late sixties induced a need for better reforestation. Besides the value increases in timber, the demand for more timber also increased. A faster timber growth required genetically improved seed for seedlings, well-prepared sites for planting, good seedling distribution on the land, and an intensive plantation maintenance program.

In order to achieve the above factors, an artificial reforestation program was needed. This program required a lot of seedlings. Such seedlings had to be produced rapidly and planted in the field using a system that was as mechanized as possible. Because of these factors, the idea of containerization surfaced more and more.

Experiments with containers continued while aerial seeding was still being practiced. These experiments began to show some advantages over bareroot seedlings in spite of the fact that the seedlings were raised in primitive facilities and often in crude homemade containers. These seedlings often showed good growth rates, high survival rates, and an excellent potential for mechanization.

The early developments made in containerization were centered mostly around the development of various types of containers. These containers came in all shapes and sizes and were made out of a wide range of materials. Some of these containers were outfitted with handling equipment. Such equipment ranged from the very simple homemade to the fully automated factory produced machines. During the early stages of containerization, mechanization seemed to be a more important concern than the biological factors needed for good seedling production. In spite of this, containerization did show a great deal of promise and it was soon obvious that containerized seedlings had some application for reforestation.

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[1] Paper presented at Southern Containerized oest Tree Seedling Conference, Savannah, Georgia, uist 25-27, 1981

[2] Philip F. Hahn, Manager, Forestry Research ergia-Pacific Corporation, P.O. Box 1618, Eugene, rgon 97440. (503) 689-1221.

The early developments that were made did not solve all the problems relating to containerization. As a matter of fact, even today we are still in the stage of sorting out the good features from all the various systems, while trying to apply these properly in the right places.

In certain areas the need for immediate and large scale seedling production triggered rapid container developments. As an example, containerized seedling production grew from less than a million seedlings to a 56 million annual seedling production rate in Oregon and Washington alone during the last decade. Similar rapid developments occurred with an earlier start in Canada and in the Scandinavian countries. Both the Canadians and Scandinavians were pioneers in large scale container developments.

THE SCANDINAVIAN PROGRAM

A major boost to early containerization was the adoption of inexpensive plastic covered greenhouses which were developed in Finland. Such facilities were used in bareroot seedling production in Finland because of their cold Nordic climate and short growing season. These and similar growing facilities later proved to be quite valuable in containerized seedling production. The Scandinavians had the desire to extend their planting season into the summer. Container grown seedlings, with their protected and undisturbed root system, proved to be more suitable for this than bareroot seedlings. There was also a need for mechanization in the Scandinavian countries and elsewhere because of high labor costs and labor shortages. This pushed the containerized seedling production in these countries to 225 million per year by 1974. This pace increased later only moderately because commercial seedling production got considerably ahead of research and development. The paper-pots became the dominant type of containers in the Scandinavian countries when containerization began on a large scale. Later it was used in other European countries and around the world.

This honeycomb shaped and accordian style container was a Japanese invention. The users of this container liked its biodegradable nature and its protection of the root system. The Japanese not only invented a container, they also invented a completely mechanized handling system. This handling system is perhaps the main reason why the use of this container gained popularity and spread so rapidly.

The facilities used for paper-pot seedling production in the Scandinavian countries were generally simple plastic greenhouse structures equipped only with the most necessary environmental control units. The trays were often placed o the ground during the nursery growing stage whic caused the containers to disintegrate prematural if they were kept too long in the nursery.

The multipot (Kopparfors) containers in Sweden helped in overcoming the premature disintegration problem but this unfortunately in turn developed new problems which is often the case in containerization.

CONTAINERIZATION IN CANADA

Canada's need for containerized seedlings materialized relatively earlier than in the United States or in other countries. The reason for this is that Canada's bareroot nursery development was further behind their seedling demand, and the Canadian's did not get involved wi aerial seeding either.

The Canadian's labor shortage in the farawa forest areas was traditionally high. Therefore, containerization in Canada seemed to be the natu thing to do, just like it was for the Scandinavi countries. The systems developed in Canada incl the following:

Bullet Planting

One of the most outstanding pioneers in Canadian containerization was Dr. John Walter, Director of the University of British Columbia Research Forest. His work dates back to the earl fifties.

Dr. Walter invented and developed the bullet method of planting. This bullet planting system was highly mechanized and was fast and efficient. The ease and speed of tree planting was a refores ation dream. It offered a good solution to the labor shortage and high labor costs in reforestin distant cutover areas. For this reason, some companies adopted the system in British Columbia during the late sixties.

Sadly to say, the field results didn't prove to be as good as the system appeared to look. Frost heaving was quite a common occurrence becau of the slick and hard container surface. The rig container restricted the roots in their growth and penetration into the forest soil. This resulted in a poor survival and growth rate.

Newer biodegradable containers are aimed to solve some of the problems in the bullet method, while still keeping its good feature of injection planting. As the initial enthusiasm for the bullet method wore off, the entire system practically faded away. However, the bullet planting system did present a lot of good ideas for the later development of other systems.

The Ontario Tube

While the bullet planting system was gaining some attention on the West Coast, something different was occurring in Eastern Canada. A tube type container was developed in the province of Ontario. The first large scale use of this spiral plastic tube was implemented in 1965.

This planting system was not mechanized like the paper pot or bullet, but some of the homemade type machines used made the system quite efficient. The tubes provided protection for the root plugs during, and shortly after planting which was important on the droughty sites where most of the seedlings were planted. This system gained acceptance in other provinces as well. Some of the disadvantages of the containers, such as root growth restriction, frost heaving, etc., turned people towards a new development in the field of containerization.

Styroblocks

The styroblock was an outgrowth of the bullet system. When the plugs were removed from the bullet container for planting, they performed a lot better in the field. This led James Kinghorn, who is with Pacific Forest Research Centre in Victoria, to the development of the styroblock container. The container and related system did not evolve overnight and, of course, did not solve all the problems relating to containerization either. Nevertheless, it was a new approach that had a lot of promise.

The styroblock, or molded polystyrene container provided good biological conditions for the seedlings during the rearing period. This resulted in an increased amount of improved seedlings compared to previous seedling crops. The better developed seedlings, when planted as naked plugs, survived well and also grew well in the field.

The mechanization process of this system came a little later. After a while, a whole range of nursery handling equipment was developed and built. With the quarterblock handling equipment, the field shipment of containers, and the process of planting directly out of the container became quite efficient. This improvement made the container recyclable from the field also.

Because of the ability of growing hardy seedlings with well-developed root plugs in styroblock containers, it is also possible to extract the plugs at the nursery without jeopordizing the seedling quality. This makes seedling shipment less costly. Extracted seedlings are also more suitable for cold storage if delayed planting is desired.

The styroblocks gained widespread acceptance in the Pacific Northwest and Canada as well as in the whole United States. They are used in other areas also.

The Spencer Lemaire Book Planters

The book planter or ROOTRAINERS as Henry Spencer likes to call his containers were developed in Alberta during the early seventies.

The containers are molded out of thin plastic sheets, while several containers are hooked together in a book form. The cavities are rectangular and slightly tapered with grooves in them for root guidance. (Other containers have root guidance abilities also)

One of the interesting features of the ROOTRAINER is that it provides a root plug inspection without removing the plug. Some other features of the ROOTRAINER include small unit handling, easy packaging, shipping, and planting.

The ROOTRAINER is a thin-walled container without any insulating capacity. Good insulation is often important to produce good hardy seedlings while the roots are protected from extreme weather conditions.

A large number of these containers are used in North America, but most of the use is in the Alberta area.

UNITED STATES DEVELOPMENTS

The first notable developements in containerization in the Pacific Northwest was the development of the Leach Cell System. During the early seventies plug seedling quality and their root system were at a rather low point. It was difficult to keep naked plugs from breaking apart. Taking styroblocks to the field at that time was cumbersome. This prompted Ray Leach to develop a container that would handle a plug in the field, while the seedlings are carried in a planter's bag, without destroying the root plugs. The idea appeared to be a rather good one in the eyes of those old time tree planters who disliked any deviation from the old planting form.

The Leach cells are injection molded out of plastic as a thin-walled container. The cells are fitted in plastic trays where they are secured firmly, but can be removed at anytime. These containers were designed to provide the ability for rearranging the cells in the frame to maximize greenhouse space usage. They are also suitable for extracting and packaging plantable seedlings while the roots are still protected by the plastic cells. These plastic cells have the capacity to be recycled for another use also.

The Leach container system gained widespread acceptance when the Weyerhaeuser Company adapted them into their containerized system in 1973. Besides Weyerhaeuser, the major users of this container are mostly located in the Pacific Northwest.

The initial excitement and acceptance of the container somewhat diminished when cost considerations were closely examined. The initial cost for the container is high, and applying some of the advantages like rearranging cells in the frame to avoid blanks, the extraction of cells for packaging, storing and field planting, and the recycling of the cells for another use all turned out to be labor intensive and costly.

The thin-walled containers didn't provide the good biological aspect for growing and protection. The aspect of freezer storing of the cells turned out to be less desirable than storing naked plugs. Naked plugs have room for expansion. Carrying seedlings in the field while still in the cells made planting slower and more difficult. So, the once highly promoted Leach cells were slowly being replaced by better and less expensive containers.

Besides the major container types just mentioned, there were also other containers developed in Canada and in the United States as well as in the rest of the world. Some of these containers include the hard plastic multipot types, plastic bags, sausage casing types, etc. The list is rather long, and I am sure I couldn't even name them all.

THE MAIN REASONS FOR CONTAINERIZATION

Some of the reasons were mentioned earlier. Besides those, the other important factors or features which were responsible for containerization can be listed as follows:

Growing Facility Features

These were at one time, and are still very important features because:

1. The growing facilities are not tied to specific ground conditions with specific soil qualities for seedling production.
2. A relatively small area is all it takes to build a facility because of its intensive usage.
3. The seedling production is not so dependent on the weather because of t environmental control systems in the growing area.
4. A relatively small facility that has production capacity of several hundre thousand seedlings and up may be cost effective.
5. The facilities can be located close t the areas where the produced seedling are used.
6. The overall cost to build a container facility is quite reasonable, in spit of the relatively expensive greenhous type growing areas.
7. The operation doesn't require large, expensive support buildings for sorti packaging, and storing seedlings.
8. There is no need for a large assortmen of cultivating and lifting equipment.
9. It takes a less expensive watering sys and a lesser amount of water than it takes in a similar capacity bareroot sery.

The factors listed for the growing facilit considerations were and are important, but ther are many more factors which favor containerizat and need to be examined before one embarks on c tainerization. These factors include:

System Mechanization Features

Components of these are:

1. Environmental controls which include heating, cooling, ventilation, and air enrichment.
2. Light, and photoperiod regulation.
3. Close nutrient supply control.
4. Easy disease and insect control.
5. Good spacing regulation through cavity sizes.
6. Mechanized sowing lines.
7. Good utilization of the facility throu thinning.
8. The ability of height, diameter, and r development control through a close mo toring system.
9. Mechanized packaging, shipping, and fi handling.

Other features which also favor containerization are:

Uniform Growth Rates

There are few culls in containers because each seedling has nearly the same amount of soi and growing space while generally receiving equa amounts of water and food.

Fast Crop Rotation

It often takes weeks to months in order to oduce a crop in containers. This, of course, pends on the species, growing regimes, and the ographical areas.

Seed Utilization

Fewer seeds are needed when producing a crop. e reason for this is because of good sowing and owing controls.

Extended Planting Season

Containerized seedlings are suitable for anting nearly all year-round. However, field isture conditions must be suitable to support edling growth.

Field Performance

Experience shows that well produced seedlings ve a high survival and growth rate in the field.

Containers for Transplants

Containerized seedlings have proved themlves to be of superior transplant stock when own for an additional year in a bareroot nury which produces large seedlings for special es.

Field Planting

Most containerized systems produce seedlings tat are easy to ship and plant manually in the fld, or by using mechanized planting equipment.

Cost Comparison

Not all containerized seedlings are cost eective. This is due to the systems and methods ud in producing and handling the seedlings. Hvever, containerized seedlings properly proded in well chosen systems are comparable in ct to bareroot seedlings. These seedlings often a less expensive, especially when their total pformance is compared which includes growing a planting, and also survival and growth rates.

During the past two decades containerized sdlings have shown many advantages but they also he their disadvantages. Nobody should have the nion that containerized seedlings solve all the pblems relating to reforestation.

To expand on this notion:

1. The relatively small containerized seedlings grown in one season or less have a smaller chance in combating heavy animal browse or severe brush competition when compared to the chance that the larger bareroot stock has.
2. Certain species shouldn't be raised in containers because they develop into better seedlings in bareroot nurseries.
3. Most containerized seedlings are bulky when shipped in containers. Shipping seedlings in containers to long distance planting sites (500-1000 km) may not be feasible.
4. Some container types are also difficult to handle when carried into the field.

Some of the advantages and disadvantages listed for containerized seedlings are not necessarily true for all of the different containerized systems.

Since there are many different containerized systems, they can not all be compared to each other straight across the board. Certain systems fit better in one area or condition than other systems. When I talk about a container system I mean more than just the container itself. My feeling or opinion is that the system includes the containers, growing facilities, handling equipment, growing regimes and growing schedules, storage of seedlings, field shipping, and planting methods.

Container systems must be chosen or designed carefully so that all of its components meet a given need while the system is biologically sound and economically feasible. There are some good systems which have been developed and have the ability to be adopted with some modification in most areas. This unfortunately wasn't true when large scale containerization started about 10-15 years ago.

One such total system is the quarterblock growing and planting system which is coupled with the shelterhouse growing facility and mechanized handling equipment. This approach looked at the total package in containerization while closely examining the local environmental conditions, crop scheduling, field conditions, and also biological and economical constraints. Experience proved this system to be quite successful, versatile, and easy to adopt in most areas with some modification. This system strongly considers a highly technical rearing practice, also.

Rearing Practices

Containerization brought a lot of technology to the field of reforestation. It also revolutionized the bareroot nursery system. Closely contolled, scientific rearing practices have taught us a lot about the seedlings need for nutrients, environment, and protection. This technology became useful for all seedling production.

Growing seedlings in containers, despite all the controls the operator has, is not easy to do.

The seedlings need a lot closer attention than they do in a bareroot nursery. A conscientious and good operator has the ability to turn the facility and technology to his favor and is able to produce excellent crops.

Poor planning in the systems development and subpar technical knowledge in growing made containerization a controversial subject. Experience has proven that the previously mentioned advantages for containerization are here. Since this field is new and is still developing, a lot of advantages are not being fully utilized yet.

CONCLUSION

In my opinion the containers are here to stay. Some major systems may fade away as they have already done so in the past and the good systems will go through more refinement. There is no doubt that along the way some more refined and newer systems will emerge.

I don't think the containers will take th place of all bareroot seedlings. However, the have replaced bareroot seedlings completely or partially in a lot of places.

Some species like true firs, hemlock, redwood, etc., are a lot easier to grow in containers than they are in bareroot nurseries. Small plugs of most species when transplanted a bareroot nursery produce a less expensive an more outstanding transplant than straight bareroot seedlings do.

Plugs have a hard time competing with 1+0 bareroots when only the growing cost factors ar considered. If the total costs including fiel handling and performance are taken into account well raised plugs will stand the test here, als

GETTING STARTED[1/]

Robert D. Raisch[2/]

John Barber, in his keynote address, uently highlighted the timeliness and the ncy of this conference. If we are to meet the hern reforestation challenge many obstacles to be surmounted. The entire forestry unity will need to use all of the methodology technology at our command. One of the major lenges facing us in the South is to supply icient numbers of quality seedlings to meet ent and future needs.

The forest industry has; and continues to enlarge its nursery capacity. The states are also attempting to expand and modernize state nurseries, but funding for the most part has been limited. Currently, many of these nurseries are producing beyond their sustainable capacities; at the cost of seedling quality. With all of our present nurseries, state and industry, producing to capacity southwide, we will still fall short of projected seedling needs.

Container-grown seedlings present opportunities to supplement bareroot seedling stock and meet special requirements. These are the issues and the opportunities we will examine now. Our first technical session will focus on container selection, seed quality and seed germination.

[1/] Presented at Southern Containerized st Tree Seedling Conference, Savannah, Georgia, st 25-27, 1981.

[2/] Area Director, State and Private Forestry, . Forest Service, Atlanta, Georgia 30367.

SELECTING CONTAINERS FOR SOUTHERN PINE SEEDLING PRODUCTION[1]

James P. Barnett[2]

Abstract.--Greenhouse and field performance data for southern pines are evaluated for a number of containers in each of three general types: tubes, plugs, and blocks. The effects of various containers on root configuration are also discussed. Recommendations for use are made, based on performance and current availability.

INTRODUCTION

Basic to any container production facility is tl selection of an appropriate container system. A ide variety of container products have been de eloped and tested for growing coniferous species i the last few years. Many of these have been de eloped for use in the northwestern United States a Canada. As interest grows and operational use o container planting increases in the southern U ted States, selection of systems appropriate to tl cultural needs and planting techniques of souther pines (*Pinus* sp.) becomes of greater concern.

In addition to evaluation of the container s tems in use in the northwestern states and Ca ada, we have sought to find and develop other s tems that may be more applicable to southern c ditions. We have tested a wide range of s tems that are in operational use as well as evalua ed a series of products that have potential for us in container planting operations.

TYPES OF CONTAINERS

The many containers that have been evaluated fo effectiveness in producing southern pine seedli gs fall into three categories: tubes, plugs, a blocks (Fig. 1). Each type has certain merits th t must be considered.

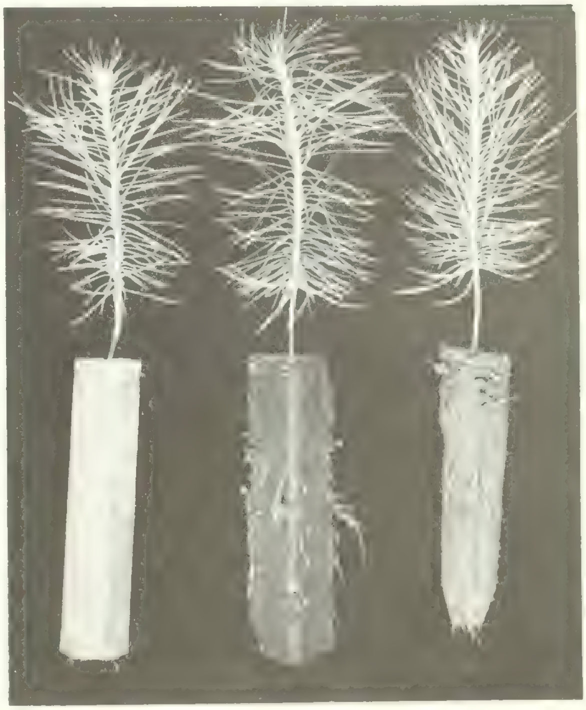

Figure 1.--Loblolly pine seedlings grown in three types of containers: (a) a biodegradable plastic tube, (b) a peat moss-vermiculite molded block, and (c) a plug from styroblock-2.

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[1] Paper presented at Southern Containerized Fo est Tree Seedling Conference, Savannah, Georgia, Au ust 25-27, 1981.

[2] Principal Silviculturist, USDA-Forest Se vice, Southern Forest Experiment Station, Pi eville, LA 71360.

Tubes

Tubes, such as Paperpots, plastic bullets, and biodegradable plastic containers, require filling with a growing medium, and have an exterior wall that is planted with the seedling. The exterior walls provide rigidity that aids in handling and planting, and give sufficient impermeability to prevent desiccation in soils that are dry near the surface (Day and Cary 1974). Their major disadvantage is that roots emerge slowly after outplanting because initial contact with the soil is made primarily through the bottom of the container.

Many of the early container systems consisted of tube-type products. One of the earliest container materials tested in the South was kraft-paper tubes. Jones (1967) successfully used spiral-wrapped kraft tubes for producing longleaf pine (*P. palustris* Mill.), black walnut (*Juglans nigra* L. and cherrybark oak (*Quercus falcata* var. *pagodifolia* Ell.) seedlings. This tube had a thick wall that decomposed slowly in sandy soils. Square tubes made from a heavy kraft paper were then tested (Fig. 2). This material folded easily for shipment, but degradation of the paper was rapid and this made planting difficult. Both types of kraft paper caused seedling chlorosis because of the utilization of nitrogen in the degradation process. The material was clearly inferior to the paper used in Japanese Paperpots, described later.

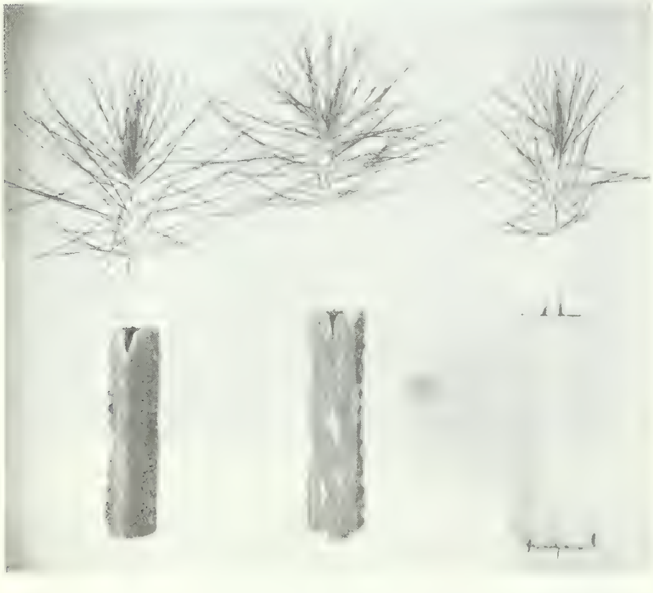


Figure 2.--Six-week-old loblolly pine seedlings growing in two sizes of Gro-blocks and in a square kraft-paper tube.

Walters' plastic bullet and planting gun t nique was another early container system (Walte 1961). Although this system has numerous desir features, such as rapidity of planting (Vyse 19 results from trials in the heavier soils common the South show that planting is difficult and r constraint restricting growth is common (Fig. 3). Because of the constraint problem, Walters (197 1978) has redesigned his bullet-shaped containe The newly designed container consists of four id cal separable sections which assemble to form a plant pot with a square cross section. To my knowledge, this new design has not been critical evaluated in the South.

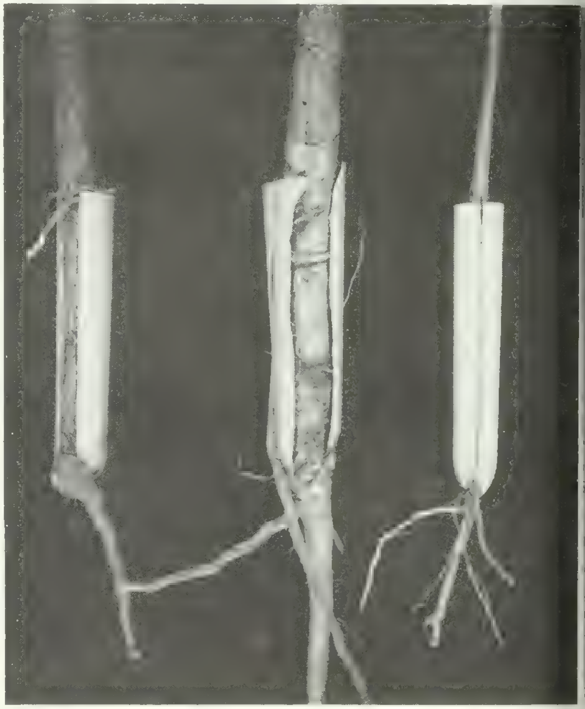
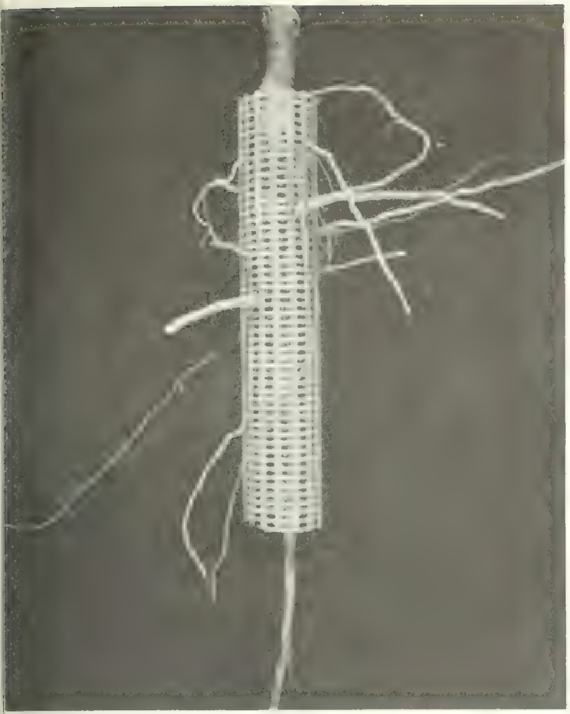


Figure 3.--Loblolly pine seedlings grown in plast bullets and excavated after 3 years. Various stages of root constraint are shown.

Another plastic material is Conwed's netlike tubing. Made of polypropylene and manufactured i various lengths, diameters, and degrees of flexibility (Schlaeger 1969), early performance was go (Miller and Budy 1974, Barnett and McGilvray 1981 However, polypropylene does not degrade and event the roots become severely constricted (Fig. 4). cause of the lack of degradation, plastic tube materials have generally not been satisfactory.



i re 4.--Conwed mesh-type container showing c nstriction of loblolly pine roots after about years after outplanting.

In the early 1970's Union Carbide Corporation ep rted that an aliphatic polyester, polycaproac one, was susceptible to attack and assimilation y icroorganisms in the soil (Potts et al. 1972). ec use of its low melting point (60° C), polycaproac one has limited usefulness for packaging at rials, but its unique properties have been va uated as a container for growing seedlings. he rate of degradation can be controlled by hi kness of the material and its dilution with ar ous additives (Clendinning et al. 1974). The io egradable plastic tubes have performed well as on ainers for growing southern pines. This is tt ibuted to breakdown in the plastic, so that oo penetration was more rapid than in the Paperot comparison (Table 1). Three months after outla ing, the plastic degraded sufficiently to ll w good root egress of loblolly pine (*P. taeda* L.) ee lings into surrounding soil (Fig. 5). There is p riod immediately after planting, however, when oo contact with surrounding soil is limited to the ot om of the tube. Although biodegradable plastic on ainers have a number of unique characteristics or container growing, the relatively high cost of ol caprolactone has discouraged complete developen of this system.

Table 1.--Survival and growth at 2-1/2 years of loblolly pine seedlings grown in biodegradable plastic and paperpot containers

Container	Soil type	Survival: June 1975 planting	Survival: August 1975 planting	Height: June 1975 planting	Height: August 1975 planting
		Percent		Feet	
Biodegradable	Silt loam	92	93	3.3	2.5
	Sandy loam	91	67	4.1	3.5
Paperpot	Silt loam	96	80	3.4	2.4
	Sandy loam	91	54	4.3	3.3

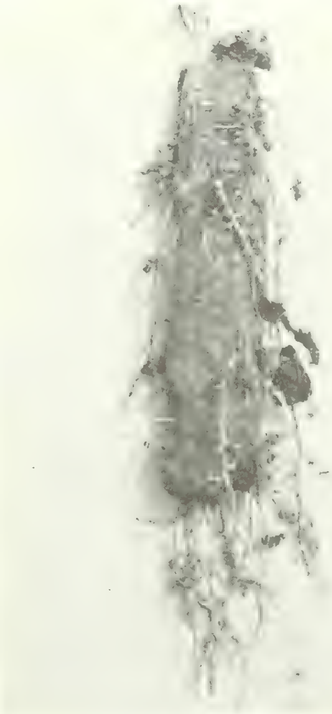


Figure 5.--Biodegradable plastic container showing root penetration of loblolly pine roots 3 months after outplanting on a silt-loam soil.

The Japanese Paperpot system has been widely evaluated in the South. It was originally developed for the sugar beet industry, but has been modified for forestry in Finland. Seedlings are grown in bottomless, hexagon-shaped individual paper tubes which contain plastic fibers and chemicals that increase their durability and resistance to soil microorganisms. Each set of tubes comes in a flat package that opens in a honeycomb fashion for filling with media. Upon watering the glue used to fasten the tubes together dissolves and they can be easily separated for planting. Paperpots vary in diameter and height; the most common types used in the South are designated 315 and 408. Most of the Paperpot material used in the South does not degrade rapidly enough after outplanting to allow root penetration of the tube walls by more than a few roots (Fig. 6). This slow root egress is most likely the reason for generally lower field survival and slower growth after outplanting (Table 2). It also causes some spiralling of the root system because the hexagonal shape tends to become cylindrical after filling. Spiralling is particularly a problem in longleaf pine where root growth is rapid. The Finnish Paperpot distributed by Lannel Tehtaat Oy is reportedly manufactured of materials that allow faster root egress.

Plugs

Plug seedlings are grown in molds, which ne to be filled with a potting medium. The rooted seedlings and growing medium are removed from co tainers and planted together. Plugs provide an biological setting for seedlings because roots a not restrained after planting and rapidly establ themselves in the surrounding soil. Plug seedli must remain in the container long enough for the root mass to bind the medium so that extraction easy. Seedlings must be extracted and packaged greenhouse sites,or containers must be returned the field. A number of different containers are available that are satisfactory.

The BC/CFS styroblock was developed in Cana by the British Columbia and Canadian Forest Serv to overcome problems inherent with plastic bulle The styroblock is a reuseable rectangular block manufactured of foamed styrene with tapered, rou cavities in which the seedlings are grown. A nu of cavity sizes are available ranging in volume 2.5 to 8.0 cubic inches. The addition of vertic ribs to the inside of the cavities has greatly reduced the root spiralling problem that is commo with cylindrical containers. However, a corkscre effect can occur at the bottom of the cavity if inadequate air movement results in improper air pruning (Fig. 7).

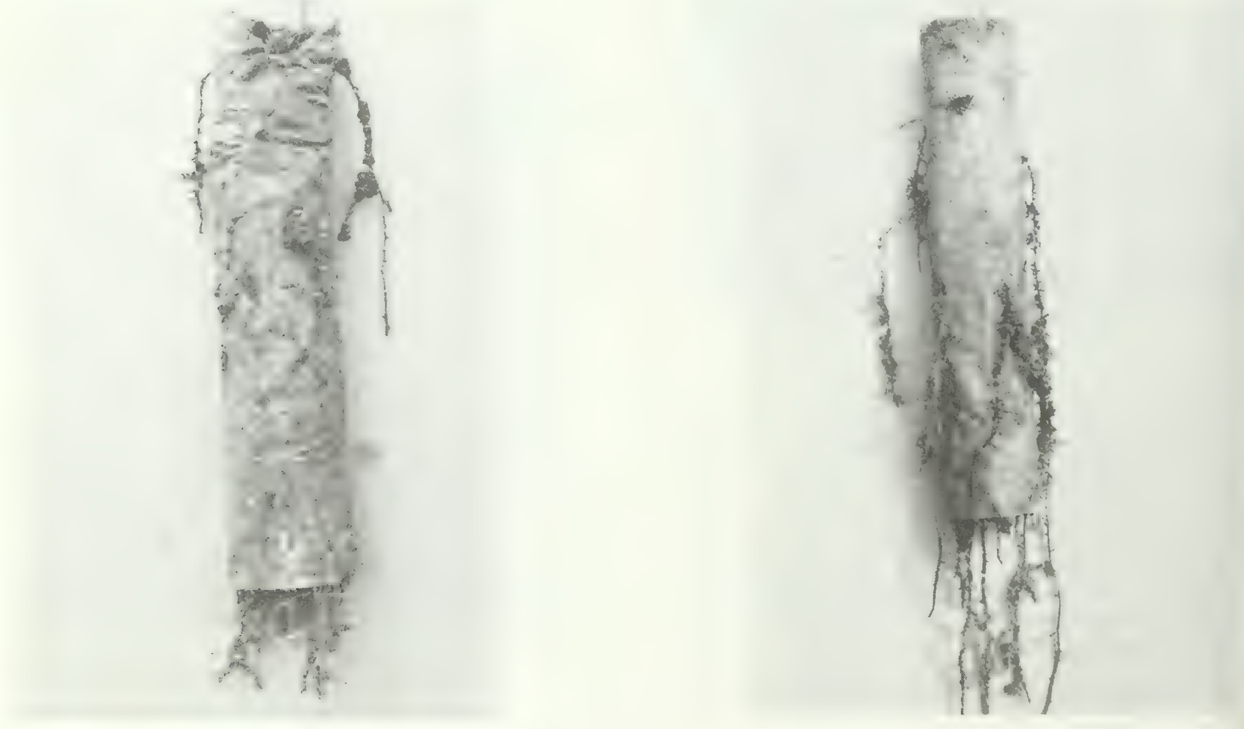
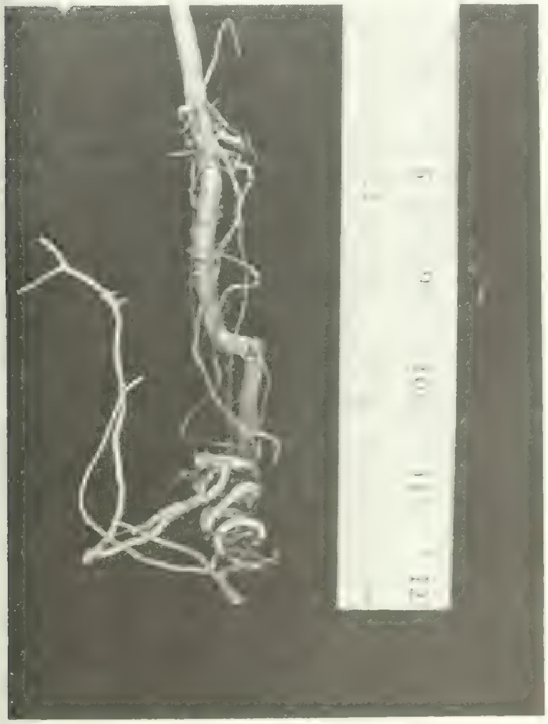


Figure 6.--Root penetration of loblolly pine through Japanese paperpots 3 months after outplanting in silt loam (left) and sandy loam (right) soils.

able 2.--Effects of container parameters on development and performance of loblolly pine seedlings

Container 1/	Container volume	Seedling density	Initial dry weight		Survival at 3+ years	Height at 3+ years
			Shoot	Root		
	In^3	Ft^2	mg	mg	Percent	Ft
			Planted 4-17-75			
ap. Paperpot	5.4	154	157	46	87	5.2
odd Planter (lg.)	4.1	29	301	86	94	5.4
odd Planter (sm.)	1.5	82	113	41	92	4.5
			Planted 6-17-75			
ap. Paperpot	5.4	154	165	46	89	4.9
odd Planter (lg.)	4.1	29	437	111	97	6.3
odd Planter (sm.)	1.5	82	227	58	99	5.6
			Planted 9-3-75			
ap. Paperpot	5.4	154	180	42	98	3.9
odd Planter (lg.)	4.1	29	470	81	97	5.1
odd Planter (sm.)	1.5	82	237	47	98	4.3
			Planted 11-6-75			
ap. Paperpot	5.4	154	124	31	83	2.8
odd Planter (lg.)	4.1	29	213	53	88	3.5
odd Planter (sm.)	1.5	82	154	34	88	3.1

/ Container parameters are: Paperpot 315 (1.2 x 6.0 inches), Todd Planter 200 (2 inches square by 3 inches high), and Todd Planter 100A (1 inch square by 3 inches high).



F ure 7.--Root systems of loblolly pine seedlings howing possible deformation at the bottom of the tyroplug where vertical ribs do not extend.

Seedlings grown in styroblocks perform well in comparison with those grown in other containers. Growth of slash pine (*P. elliottii* Engelm.) seedlings after outplanting from several containers showed that those from Styroblock-2 equalled or excelled all others except Keyes Peat Sticks (Table 3). An earlier test comparing survival and growth of loblolly pine seedlings from Styroblock-2 containers with those of other container types showed good performance under the stress conditions of summer planting (Table 4).

Other plug systems like RL Single Cells and Spencer-Lemaire Rootrainers have the advantages of plug-type containers and perform well. Each specific container has certain characteristics that make it unique. The RL Single Cells can be handled individually for randomization, removal of blanks, and transport. Rootrainers open to allow checking of the root system and easy removal of the plug.

The Todd Speedling System is another promising system. Its cavities are square and their obtuse taper makes extraction easy (Fig. 8). Another feature that improves seedling quality is low density (number per unit area) in relation to cavity volume--50 seedlings/ft^2 and 4.6 in^3 per cavity. When loblolly pine seedlings were grown in this and several other containers, initial seedling development and

Table 3.--Survival and heights of slash pine (*Pinus elliottii* Engelm.) seedlings grown in various container products 1+ years after outplanting

Container	Survival (1/76) after planting on 4-26-74	6-25-74	8-28-74	Heights (1/76) after planting on 4-26-74	6-25-74	8-28-74
	--------Percent--------			---------Feet-----------		
Gro-block	69	57	89	2.4	1.6	1.3
Peat stick	91	94	100	3.2	1.8	1.7
Paperpot (315)	81	76	96	2.1	1.5	1.5
Styroblock-2	89	93	98	2.5	1.6	1.4
Rootrainer (Ferdinand)	83	71	98	2.7	1.6	1.4

Table 4.--Survival and heights of loblolly pine seedlings grown in several types of containers and measured after 30 months in the field 1/

Container	June 21, 1972, planting: Survival	Height	August 24, 1972, planting: Survival	Height
	Percent	Feet	Percent	Feet
Plastic bullets	77	2.7	19	1.3
Kraft paper	55	2.4	47	1.4
Paperpot	64	2.5	49	2.0
Polyloam blocks	52	2.8	12	1.2
Styroblock-2	96	3.0	79	2.2

1/ Except for those in polyloam blocks, all seedlings were grown in a commercial potting medium with relatively low fertility levels.

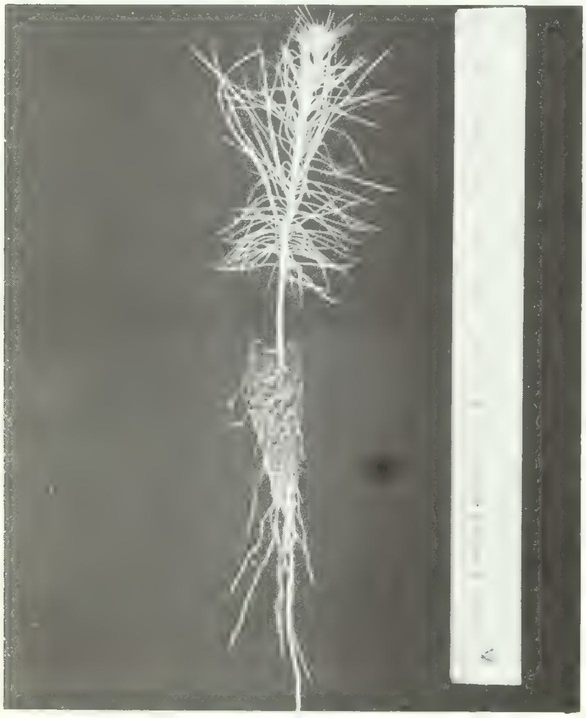


Figure 8.--Root extension of a loblolly pine seedling grown in a small Todd Speedling Tray (2.5 cm or 1 inch square by 7.6 cm or 3 inches deep) 2 weeks after planting into a sawdust bin.

field survival indicate that this system pro seedlings equal or better than others tested (Table 5). Because of the obtuse taper the lings are difficult to package once they are removed from the block.

Table 5.--Development and field performance of loblolly pine seedlin in various containers and outplanted on several dates

Container	Seedling development: Heights	O.D. top wt.	O.D. root wt.	Field perform (Jan. 1980): Survival
	Inches	--------mg--------		Percent
		May 22, 1978, Planting		
Jap. Paperpot (315)	8.7	473	78	89
Tree Planter (ITW)	8.4	558	111	91
Tree-Start	7.4	429	-- 1/	99
Styroblock-4	9.3	698	140	94
Todd Planter (150-5)	9.9	682	133	98
Gro-block (large)	9.5	603	--	80
		June 15, 1978, Planting		
Jap. Paperpot (315)	7.6	333	58	27
Tree Planter (ITW)	5.9	324	68	64
Tree-Start	7.0	385	--	63
Styroblock-4	8.0	468	87	61
Todd Planter (150-5)	7.3	515	116	71
Gro-block (large)	8.3	424	--	43
		August 23, 1978, Planting		
Jap. Paperpot (315)	7.7	460	113	77
Tree Planter (ITW)	3.7	257	145	77
Tree-Start	8.9	895	--	68
Styroblock-4	7.1	555	188	67
Todd Planter (150-5)	6.5	660	224	83
Gro-block (large)	8.5	678	--	57
		November 17, 1978, Planting		
Jap. Paperpot (315)	6.5	410	79	25
Tree Planter (ITW)	6.6	368	114	34
Tree-Start	6.1	782	--	23
Styroblock-4	5.5	513	176	47
Todd Planter (150-5)	4.4	482	158	31
Gro-block (large)	6.5	648	--	20

1/ A dash indicates that no data could be collected on root weights be of the type of container.

Blocks

The block is both the container and the gr ing medium. Seeds are sown in the block and th entire package is later transplanted into the f Because blocks are usually rigid enough for mech nized planting, but still allow rapid root egres after outplanting, they have advantages of both tubes and plugs.

Although numerous block-type products have evaluated, only a few have been available for us large-scale programs. One type of self-containe block container consists of acrylonitrile-bonded softwood pulp (Schneider et al. 1970, White and Schneider 1972). This product, originally manufactured by American Can Company under the trade name of BR-8, was later made by Famco, Inc., and called Gro-block (Fig. 2). Six-week-old loblolly pine seedlings grown in these soilless blocks an outplanted in July survived better and grew fast than seedlings grown in soil-filled Kraft paper tubes (Barnett 1975). However, when older seedlings were grown in comparative containers, survi and growth of seedlings in Gro-blocks were genera poorer than in other containers (Table 3). This poorer performance may reflect the small size of

se Gro-blocks when compared to the other products
ted. Gro-blocks are not now commercially avail-
le and further development work is needed before
system is a viable one.

Probably the most promising block-type container
luated has been developed by Keyes Fibre Company.
block consists of a blend of sphagnum peat moss,
miculite, cellulose fibers, and nutrients. An
ly design of this product was rectangular in
ss-section (1-1/8 x 1-1/4 inches) and 6 inches
g. This block, termed a "Peat Stick" was used
several studies with good results (Table 3).
olly and slash pine seedlings grown in this
k survived and grew better than those in other
ainers, particularly when outplanted under con-
ions of moisture stress (Fig. 9 and 10). Sur-
l was maintained at a high level even during
, July, and August, when survival of seedlings
n in Gro-blocks and Paperpots dropped. Heights
eedlings outplanted in Peat Sticks in June com-
d favorably to those of bare-root seedlings
ted in the previous March.

Because of the success with Peat Sticks, the
uct was redesigned to provide for easier hand-
, packaging and outplanting. The resulting
Tree-Start has a smaller volume, but has the
properties. The advantages of the Tree-Start
udes: (1) simplified greenhouse operations
use no filling is required, (2) no root
pulation into undesirable patterns or con-
int after outplanting, and (3) adaptability to
anized planting equipment. After outplanting,
egress occurs from the entire block surface
no unusual patterns of root development are
ent that should cause future problems in seed-
growth or stability (Fig. 11). The blocks
subject to development of a saprophytic mold
ng the early greenhouse period and some root
s-over occurs along the back of the 10-block
p if seedlings are held for long periods.
further development could make this an
llent product, but at the present time in-
ficient demand exists to keep this product
lable.

Other Containers

Numerous container materials other than those
ribed have been evaluated (Barnett and McGilvray
). Some of these have promise but for some
on have not been produced for commercial use.
experience with a wide range of containers
ld provide the information necessary to antici-
the performance of other containers not
rted here.

CONTAINERS AND ROOT FORM

When planting any tree you risk having a root system that is deformed, at least to the extent that it will not have the same root configuration as trees grown from seed in place. Recently a Symposium was held devoted to the evaluation of root form on plant development (Van Eerden and Kinghorn 1978). However, there is still no clear determination of effects of root malformation on seedling performance.

Our results with southern pines indicate that the severe constraint of many of the tube-type containers may adversely affect seedling growth. For example, plastic bullets can limit root egress to the extent that growth is stunted (Fig. 3). Other containers can result in root strangulation (Fig. 4) or root spiralling. If, however, these obvious extremes of deformity are avoided, the configuration imposed by the container may not be harmful. Block-type containers seem to impart less of an "oriented" root system than bare-root planting. Root egress from blocks such as Kys-Tree-Starts occurs from the entire surface of the block in a natural manner (Fig. 11).

The effect of plug-type containers on root configuration can vary greatly. Round cavities, like in the Styroblock container, can result in root spiralling if vertical ribs are not incorporated to force root growth downward. These ribs are effective in reducing root spiralling.

Studies have also shown that there are differences among species and soil types in the amount of root malformation. Longleaf pine is more susceptible to root spiralling than loblolly or slash, probably because the lack of stem growth results in more rapid root elongation. Heavy soils can also increase the amount of root malformation by limitint rapid root egress through the punched planting hole wall (Barnett 1978). Root spiralling can occur within the planting hole when holes are punched in heavy clay soils. However, with reasonable precautions in selection of containers and planting techniques, root configuration should not adversely affect seedling growth and development.

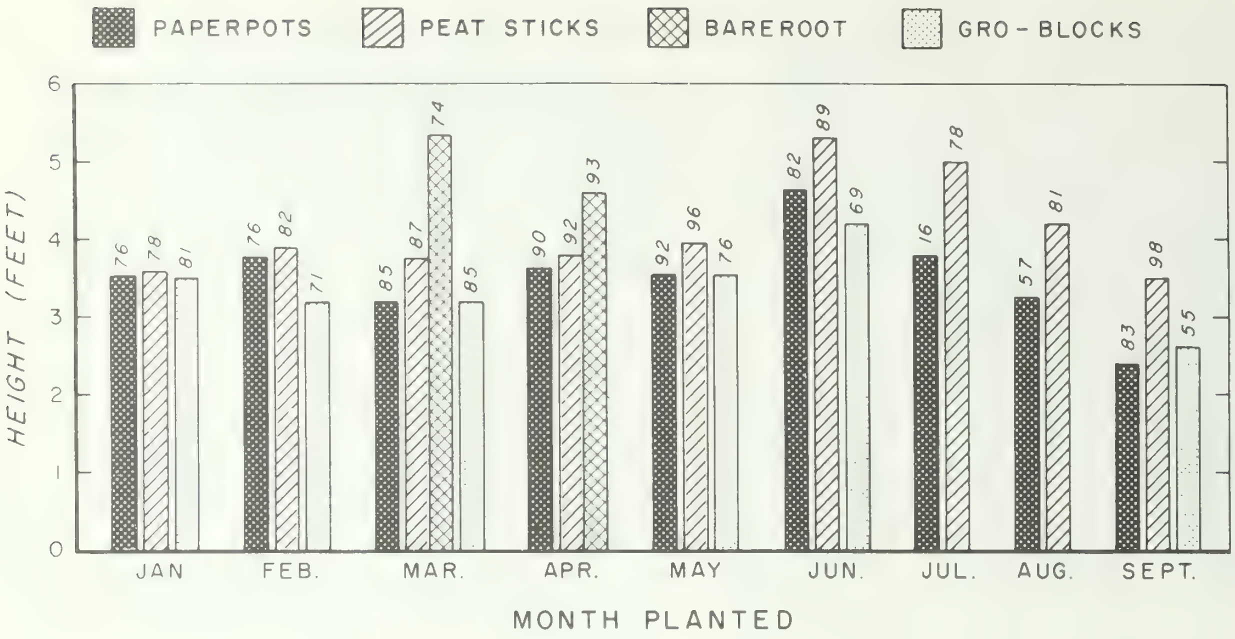


Figure 9.--Heights and survival (above bars) of slash pine seedlings planted during CY 1973 and measured during January 1976.

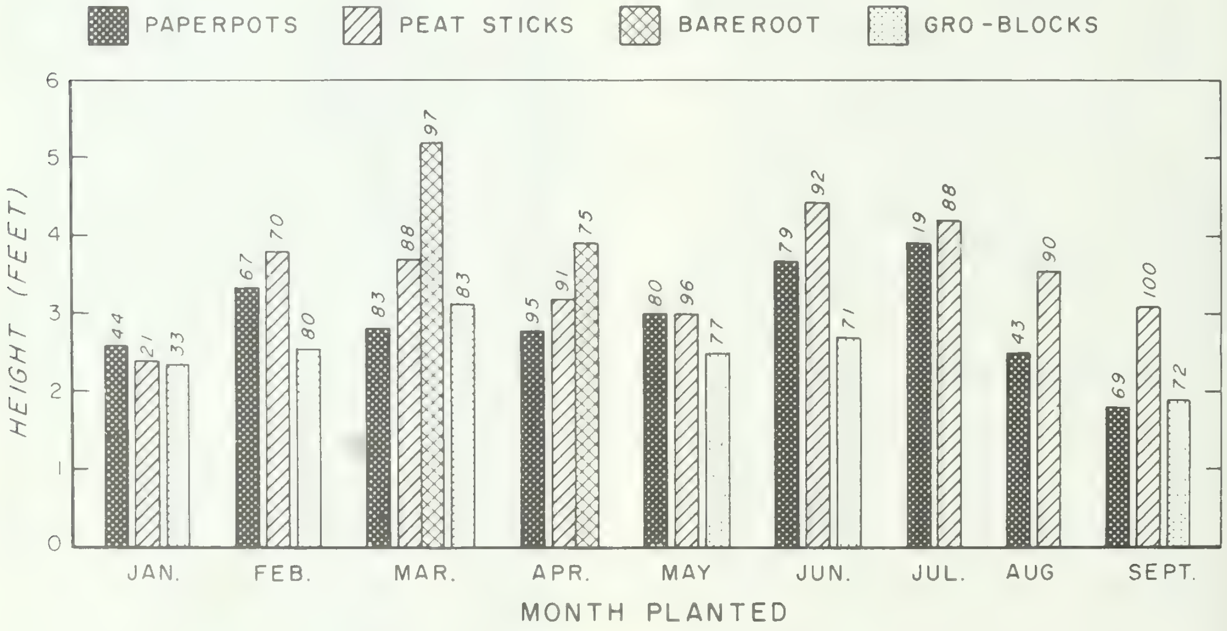
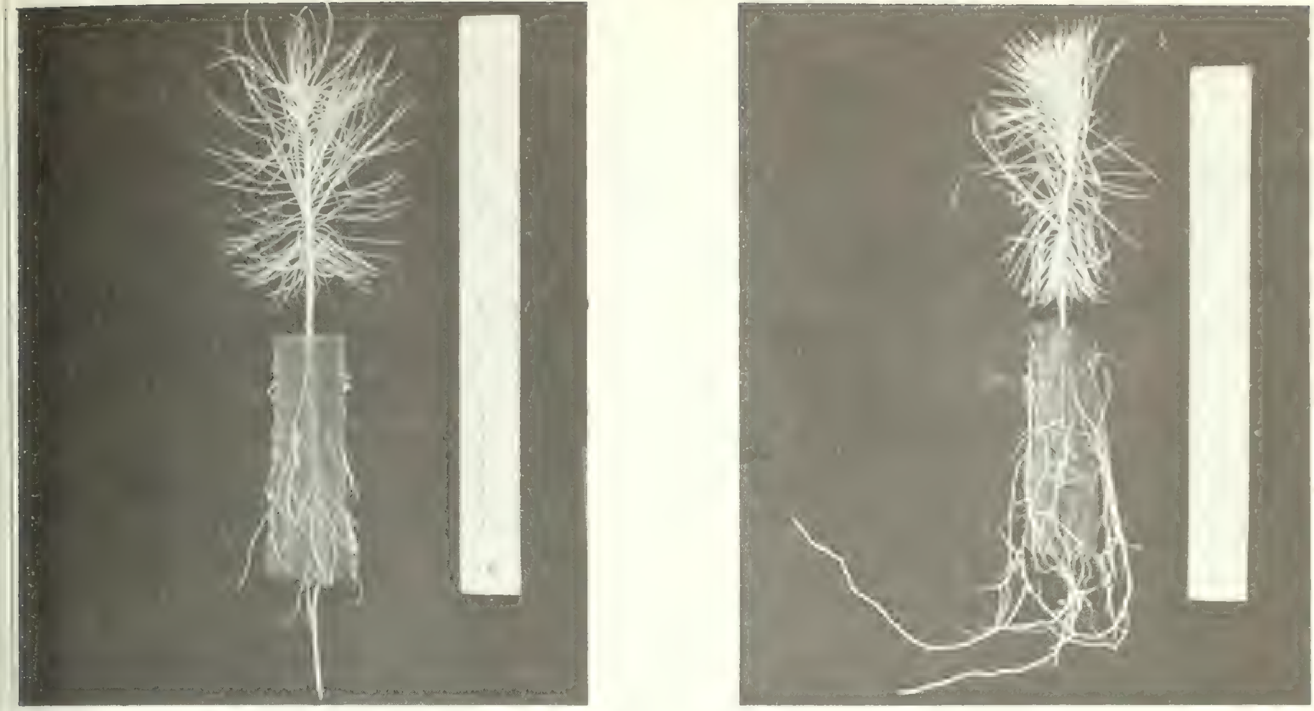


Figure 10.--Heights and survival (above bars) of loblolly pine seedlings planted during CY 1973 and measured during January 1976.



Fure 11.--Development of loblolly pine seedlings in Kys-Tree-Starts 2 weeks (left) and 4 weeks (right) fter outplanting into a sawdust bin.

RECOMMENDATIONS FOR THE SOUTH

The choice of container system depends on a nuber of variables: facilities, size and species oi seedlings to be grown, planting techniques and ecipment, and personal preference.

Species such as longleaf pine, that are very iolerant, should be grown in containers that alow a smaller number per unit area than most other ccifers. Larger containers are also desirable when sedlings of larger than usual size are to be produed. Seedlings grown for hand-planting operations ca utilize plug-type containers that could be less deirable for more automated planting equipment.

The recommendations of container systems that folow are based on performance evaluations with sothern pines and on commercial availability.

Tubes.--The Paperpot is the best of the tubety containers now available that have been tested wih the southern pines. The Finnish Paperpot is proably superior to the earlier material used in th South since there is less restriction to root petration in the Finnish product.

Blocks.--The Kys-Tree-Start is the best perfoing block material tested. Field performance ofthis material is good and it is easily adaptable to nore automated planting equipment. However, at th present time this product is not commercially avlable.

Plugs.--There are no great differences among the plug-type containers in field performance. Most of the variations in performance are more of a reflection of cavities per unit area than container, per se. The differences in the various products are primarily in handling features, i.e., some open for ease of extraction, others can be separated for ease of shipping.

Although a wide variety of container products have been evaluated during recent years, the actual availability of good performing products designed for southern conditions is limited. This reflects the relatively small production of container-grown seedlings in the South. As the quantity of seedlings produced increases, further development and manufacture of the promising container systems will occur.

LITERATURE CITED

Barnett, James P.
1975. Containerized pine seedlings thrive in wood-fiber blocks. U. S. Dep. Agric. For. Serv., Tree Planters' Notes 26(2):13, 20-21.

Barnett, James P.
1978. Advances in container production of planting stock. In Proc. of the Fifth North American Forest Biology Workshop, p. 167-175. Gainesville, FL.

Barnett, James P., and John M. McGilvray.
1981. Container planting systems for the South. U. S. Dep. Agric. For. Serv. Res. Pap. SO-167, 18 p. South. For. Exp. Stn., New Orleans, La.

Clendinning, Robert A., Steven Cohen, and James E. Potts.
1974. Biodegradable containers: degradation rates and fabrication techniques. Proc. North Am. Containerized Forest Tree Seedling Symp., Great Plains Agric. Counc. Pub. 68: 244-254.

Day, R. J., and J. R. Cary.
1974. Differences in post-planting soil-moisture relations of container-grown tube and plug stock affect the field survival and growth of black spruce. In Proc. North Am. Containerized Forest Tree Seedling Symp., Great Plains, Agric. Counc. Pub. 68:388-392.

Jones, LeRoy.
1967. Tubed seedlings. Forest Farmer 26:10-11, 18.

Miller, E. L., and J. D. Budy.
1974. Field survival of container-grown Jeffrey pine seedlings outplanted on adverse sites. Proc. North Am. Containerized Forest Tree Seedling Symp., Great Plains Agric. Counc. Pub. 68:377-383.

Potts, J. E., R. A. Clendinning, and W. B. Ackart.
1972. An investigation of the biodegradability of packaging plastics. U. S. Environmental Protection Agency Report EPA-R2-72-046.

Schlaeger, Gary D.
1969. Improved plastic tubes for seedlings. U. S. Dep. Agric. For. Serv., Tree Planters' Notes 19(4):11-12.

Schneider, G., D. P. White, and R. Heiligman.
1970. Growing coniferous seedlings in soilless containers for field planting. U. S. Dep. Agric. For. Serv., Tree Planters' Notes 21(3):3-7.

Van Eerden, Evert, and James M. Kinghorn.
1978. Proceedings of the root form of planted trees. Brit. Columbia Minist. of Forests/Canad. Forestry Serv. Joint Report 8, 357 p.

Vyse, A. H.
1971. Planting rates increased in British Columbia with new planting gun and bullets. U. S. Dep. Agric. For. Serv., Tree Planters' Notes 22(1):1.

Walters, J.
1961. The planting gun and bullet: a new planting technique. Forest. Chron. 37: 94-95, 107.

Walters, J.
1974. Engineering for injection planting. Proc. North Amer. Containerized Forest Tr Seedling Symp., Great Plains Agric. Counc Publ. 68:241-243.

Walters, J.
1978. A planting technique for eliminating root deformation. Proc. Root Form of Pla Trees Symp., Brit. Col. Ministry of Fores Canadian Forestry Serv. Joint Report 8: 301-305.

White, D. P., and G. Schneider.
1972. Soilless container system developed growing conifer seedlings. U. S. Dep. Agr For. Serv., Tree Planters' Notes 23(1):1-

YOU REAP WHAT YOU SOW [1]

E.W. Belcher [2]

Abstract.--This paper presents methods of evaluating seed quality, identifying losses of quality, and describes five techniques to improve seed quality. These techniques include: water soak, stratification, pathogen control, increased germination temperatures and seed sizing.

INTRODUCTION

An efficient container operation requires a minimum of blanks and multiple seedlings. This efficiency may only be acquired with high quality seed and improved germination techniques (Pawuk and Barnett 1979). The best techniques and resulting seed involve procedures discussed in this report: evaluating seed quality, identifying losses of quality, and techniques to improve seed quality. Recommendations are given on seed handling for container culture.

SEED EVALUATION

The most commonly used evaluation of seed viability is germination. Germination is measured by the percentage of seed which will germinate per 100 seed. The percentage is calculated from standard laboratory tests which are conducted under optimum conditions. The data must be adjusted to prevailing nursery conditions. In the nursery, the adjustment is called survival percent and is obtained from history plot data (Belcher 1964), but such data are limited with container stock.

Experience has shown that the faster the seed germinate, the higher the survival (Rohmeder 1962; Larson 1961). The speed and ability of a seed to germinate identify the seed strength which we call vigor (Hartman and Kester 1975). It is easier to describe vigor than it is to measure it. Declining vigor ultimately leads to low germination and a lowered ability of seedlings to withstand unfavorable conditions. As vigor decreases, the difference between laboratory and field germination increases. This difference is due, in part, to the fact that death is the result of a continuing progression in aging (Justice and Bass 1978, Belcher 1978).

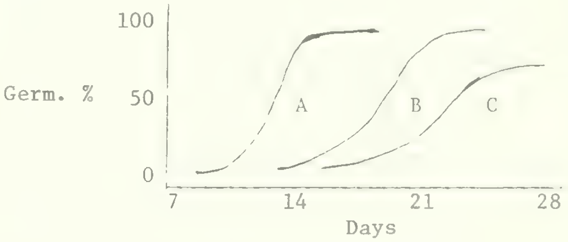


Figure 1.--Germination curve of three selected seed lots.

One method of evaluating seed vigor is by plotting a germination curve (fig. 1). Seed with high vigor (A) germinate rapidly. As vigor decreases (C), so does potential germination and the rate of that germination. Two stratified lots may provide similar total germination (A and B) but one lot may have a delayed germination (B). This delay may be due to weaker seed or seed dormancy, but whatever the cause, fewer seedlings will be produced when subjected to adverse field conditions.

Other methods include the "Coefficient of Velocity" (Kotowski 1926); the "Germination resistance" (Gordon 1973); the Weibull Function (Bonner 1976), accumulative germination by size classes (Wang 1973) and the "Germination Value" (Czabator 1962). "Germination Value" is the easiest to use, and therefore merits a little more discussion.

This index combines the rate of germination with germinative energy. Because of the emphasis on the rate of germination, this index has considerable merit in evaluation of seed for container stock. As an example, this technique is applied to the curves in figure 1 (see table 1).

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[1] Paper presented at Southern Containerized Forest Tree Seedling Conference, Savannah, Ga. August 25-27, 1981.

[2] Staff Director, National Tree Seed Laboratory, Macon, Ga. The Laboratory is operated cooperatively by Southeastern Area, USDA Forest Service and the Georgia Forestry Commission.

The germination value more clearly expresses the earlier description we presented of the germination curves in figure 1. Maximum output of seedlings at a minimum cost will require high germination values.

Table 1.--Germination data on three selected lots, with germination value

Recording date	Seed lots A	B	C
	Germination %		
7	14	0	0
14	78	14	4
21	82	79	22
28	82	81	69
Germination reported	82	81	69
Germination value	16.3	10.9	6.0

CAUSES OF LOW SEED VIGOR

The causes of low vigor (Heydecker 1972 and Hartman and Kester 1975) are the same causes that lead to low viability. Most of these problems can be avoided if you recognize the causes, described in the following sections.

Physiological

When fruits are collected prior to natural maturity they may produce physiologically immature seed. The earlier the collection, the more immature the seed. Similar instances may occur with extreme adverse weather conditions that may delay or prevent natural maturity.

Mechanical

As the future potential of our forests, tree seed should be considered as fragile as eggs. Unfortunately, the careless slam-bang processing used in many plants is destructive to the seed. Damage ranges from obvious mechanical breaks in the seed coat to subtle impact damage. An impact or blow to the seed results in a bruise. This bruise can result in death if it involves a large enough area or includes the delicate radicle. The result of impact damage may not be evident for six months to a year. I have seen impact damage so great that embryos were broken in half (visualized on radiographs) while no external damage was visible.

Microbial

The air around us is full of fungal spores. The concentration and variety of these spores may be changed by the introduction of infested fruits, seedlings or other living, dying or dead plant material. The rough texture of the seed coat makes a good resting place for microscopic spores, especially those with hooks, barbs, or adhesive qualities. The spores remain until conditions are optimum for their germination. If they are saprophytic, they live only on dead seed and cause no real problem. But, if they are parasitic, such as _Fusarium_ sp., they may spread rapidly and kill seed before, during, and even after germination.

Also, fungal organisms that enter the seed through breaks in the seed coat, insect holes and other means have been reported in seed tests.[3] Once inside the seed, they initiate deterioration, dissolving the tissue for their own use.

Cytological

"A plant cannot be better than the seed from which it was grown," said Heydecker (1972). Seeds are at their physiological peak at maturity (Justice and Bass 1978). From that point on, vigor declines because of the aging process until death occurs. However, at some point well before death the planting value of seed is questionable. The reduced vigor results in a greatly reduced germination when adverse field conditions are imposed.

Morphological

Strange things happen because of environmental influences during seed production. The longer the developmental process the greater the environmental influence. The greatest influence observed is seed size. Research has shown large seed germinates faster than small seed (Heydecker 1972 and McDaniel 1973) when all else is equal. Delays in field germination subject seed to greater environmental stress and thereby lower stand densities.

Genetics

Delays in germination may be caused by seed dormancy which varies by clone. When bulk seed is sown, the clonal variation is maximized. Sowing individual clones minimizes variation and maximizes plant survival (Wasser 1978). Also, the wrong combination of genetic material can lead to seedlings that germinate well, but which are susceptible to adverse weather or that, in the case of those devoid of pigmentation, cannot survive under the best conditions.

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[3] Fungal survey conducted by E. Belcher, R. Anderson and T. Miller, 1979-80 (unpublished)

INVIGORATION

Assuming you have the best seed you can produce, ıd can you make it produce the maximum number of edlings? Five methods useful in promoting higher duction of container stock will be discussed.

Water Soak

Seeds must become imbibed before they will ger- iate. If dry seed are planted, the seed must nibe the moisture from the soil. Imbibition is uh slower in soil than in a water soak. Full nibition of the seed at planting can increase the ped of germination. Faster sprouting will occur ih seed that are difficult to germinate by soaking hn in aerated water (Barnett 1971). Once seed are lnted in a moist condition, they must be kept ost if maximum germination is to be realized. ost seed placed in a dry environment will decrease nability to germinate with time until the seed osture content has reached equilibrium with the xsting atmospheric conditions (Forrest 1964).[4]

Stratification

The most accepted means of promoting germinative ngy and the rate of germination is with some nrval of stratification. The seed must be fully mlbed to effect stratification. The rate of ger- irtion can even be increased for seed which are otnormally dormant by a 14-day stratification eiod, but this treatment may reduce total germina- ic.[5] Care should be taken not to stratify seed o ong that they germinate during treatment. Some peies, (such as loblolly pine and Douglas-fir) can e artially dried following stratification and tced for 6 months to a year if conditions are not avrable to sowing (Danielson and Tanaka 1978; elher 1981).[6]

Pathogen Control

Saprophytic fungi are forever present, but be- aue they live on dead and dying tissue they usually aybe ignored. On the other hand, a pathogenic uni such as *Fusarium* sp. can be disastrous when aried into a seed bed or container via the seed Pak 1978). They spread so rapidly, the devasta- io may be overwhelming before it's identified. ecise of the intensive management of container tox, take some precautions to reduce the amount f ngal spores carried into planting (Carlson 1979). Most of the existing spores can be removed by a vigorous water rinse (Belcher 1981). A partial degree of sterilization can also be obtained by limited soaks in bleach or peroxide (Barnett 1976). Caution must be exercised because these chemicals are toxic to seed tissue and can reduce germination if the seed is soaked too long. More permanent treatment requires the use of a fungicide. If fungicides are used, apply them following stratification rather than prior to it because most fungicides are toxic to seed tissue and can be absorbed into the seed, once dissolved (Pawuk 1979).

Increased Temperature

Each species has an optimum temperature that will provide maximum germination. The best temperature is usually a little higher or lower than the seed experiences in its natural habitat. Nearly all seed will germinate at an alternating 20°-30°C since this is very close to that occuring in nature. Research has shown that constant temperatures often promote faster germination, but as the temperature is increased the weaker seed do not develop normally (Belcher 1966 and Barnett 1979). As an example: loblolly pine germinates well at 20°-30°C in 28 days. At 22°C, loblolly will reach maximum germination in 21 days and at 28°C it will reach maximum germination in 14 days. The germination capacity at 28°C will be less than that at 22°C if the lot has been stored because the weak seed do not survive or germinate abnormally. The germination rate of container stock can be increased by setting a slightly elevated constant temperature until germination can be observed and then changed to an alternating temperature for sturdy growth. Mean constant temperatures should be below 27°C.

Seed Sizing

Seed sizing can be used effectively in a container program because each size can be treated to effect maximum germination of that size. Large to medium-large seed usually germinate the fastest and small seed the slowest. Also, small seed usually contain the most dormancy (Choi and Kim 1969).

Contrary to the argument that sizing may eliminate clones (Silen and Osterhaus 1978), no genotypes are lost unless one or more sizes are discarded. With the present value of improved seed, the loss of clones does not seem likely. The real benefit in seed sizing is a more uniform germination which provides more efficient utilization of improved seed.

CONCLUSION AND RECOMMENDATIONS

A container operation must be flexible enough to respond to changing demands, but there is a point at which the cost is greater than the investment.

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[4] Belcher 1967 unpublished laboratory study

[5] Belcher 1969-unpublished laboratory findings it Mississippi longleaf pine

[6] Belcher 1981-manuscript being reviewed

This point usually occurs when production is decreased by poor quality seed and inadequate seedling production. The container operation manager can improve the operation by selecting the best quality seed available. If the seed is not the best, the deficiency should be evaluated. With this knowledge, reclean the seed, replace the seed and/or promote the existing viability.

Once the seed has been upgraded and tested, apply the necessary techniques to promote the germination. A stratification of 14 days or more may be helpful, depending on the species, but if time is critical soak the seed overnight in water. Apply pathogen control if seed mold was identified in the seed test. And finally, maintain a little higher than normal greenhouse temperature until germination begins. Take care to avoid constant temperatures above 27°C.

In summary, you can only reap what you sow. Use the best quality seed possible!

LITERATURE CITED

Barnett, J.P.
1971. Aerated water soaks stimulate germination of southern pine seeds. USDA For. Serv. Pap. SO-67, 9 p. South. For. Exp. Stn., New Orleans, La.

Barnett, J.P.
1976. Sterilizing southern pine seeds with hydrogen peroxide. Tree Planter's Notes 27(3):17-19.

Barnett, J.P.
1979. Germination temperatures for container culture of southern pines. South. J. Applied For. 3(1):13-14.

Belcher, E.W.
1964. The use of history plots in the nursery. TPN 64:27-31.

Belcher, E.W.
1966. Influence of light, temperature and stratification on loblolly and slash pine seed germination. Proc. AOSA 56:89-94.

Belcher, E.W.
1978. Aspects of seed quality. Int. Mt. Nurserymen's Conf. Proc. Sect. D. p. 54-60. USDA For. Serv., S&PF, R-5, San Francisco, Ca.

Belcher, E.W.
1981. 21st National Tree Seed Laboratory Report. 43 p. USDA For. Serv., S&PF, R-8, Atlanta, Ga.

Bonner, F.T.
1976. The Weibull Function: A new method of comparing seed vigor. J. Seed Tech. 1(1):96-103.

Carlson, L.W.
1979. Guidelines for rearing containerized conifer seedlings in the prairie provinces. Info. Report NOR-X-214, North. For. Res. Cent., Edmonton, Alberta, C.

Choi, S.K. and K.C. Kim.
1969. Studies on the characteristics of selected plus-tree. II. The difference in seed germination capacity between plus-tree clones. Res. Rep. Inst. For. Genet. Korea No.7 p.81-90.

Czabator, F.J.
1962. Germination Value: An index combini
and completeness of pine seed germination.
Sci. 8(4):386-396.

Danielson, H.R., and Y. Tanaka.
1978. Drying and storing stratified ponder
pine and Douglas-fir seeds. For. Sci. 24
16.

Forrest, W.G.
1964. The effect of changing moisture conte
the germination of slash pine seed. Austr
For. p.277-286.

Gordon, A.G.
1973. The rate of germination In W. Heydeck
(ed.) Seed Ecology. Penn. State Univ. Pre
University Park, Pa. p.391-410.

Hartmann, H.T., and D.E. Kester.
1975. Plant propagation: Principles and pr
Third ed. Prentice-Hall Inc., Englewood Cl
N.J. 662 p.

Heydecker, W.
1972 Vigour In E.H. Roberts (ed.) Viability
seeds. Syracuse, N.Y. p. 209-252.

Justice, O.L., and L.N. Bass.
1978. Principles and practices of seed stor
USDA, Agric. Handb. No. 506. Washington, D
289 p.

Kotowski, F.
1926. Temperature relations to germination
vegetable seeds. Proc. Amer. Soc. Hort. Sc
23: 176-184.

Larson, M.M.
1961. Seed size, germination dates, and sur
relationships of ponderosa pine in the Sou
USDA For. Serv., Rocky Mtn. For. Rnge. Exp
Res. Note 66, 1 p.

McDaniel, R.G.
1973. Genetic factors influencing seed vigo
biochemistry of heterosis. Seed Sci. & Tec
1(1):25-50.

Pawuk, W.H.
1978. Damping-off of container-grown longlea
pine seedlings by seedborne Fusaria. Plant
Reporter. 62(1):82-84.

Pawuk, W.H.
1979. Fungicide coverings affect the germina
of southern pine seeds. TPN 30(1):3-4.

Pawuk, W.H. and J.P. Barnett.
1979. Seed handling practices for southern p
grown in containers. South. J. of Applied
3(1):19-22.

Rohmeder, E.
1962. Die bedeutung der keimschnellighirt be
stlichen samenarten. Proc. ISTA 27(3):657-

Silen, R.R., and C. Osterhaus.
1978. Reduction of genetic base by sizing of
Douglas-fir seed lots. Int. Mt. Nurserymen
Conf. Proc. Sect. D., p. 38-48. USDA, S&PF
R-5, San Francisco, Ca.

Wang, B.S.P.
1973. Laboratory germination criteria for re
pine seed. Proc. AOSA 63:94-101.

Wasser, R.G.
1978. Tree improvement research: Pure vs ra
dom sowing study. Proc. So. Nursery Conf.
Tech. Pub. SA-TP6. USDA For. Serv. Southea
Area, Atlanta, Ga. p. 15-19.

SEED SOWING STRATEGIES FOR CONTAINERIZED SEEDLING OPERATIONS[1]

William D. Pepper and James P. Barnett[2]

Abstract.--Choosing a container sowing strategy was formulated as a linear programming problem. An optimal sowing strategy is achieved by choosing the three fractions of containers sown with one, two, and three seeds to minimize an economic penalty function, which penalizes a sowing strategy if it does not deal effectively with problems caused by blank cells. Mixed sowing strategies, as opposed to the standard strategy of sowing two seeds per cell, were generally optimal.

INTRODUCTION

Because of the relatively high cost of grow- n seedlings in containers compared with bare- oo programs, methods are needed to make all h es of the container operation as efficient as o ible. One significant efficiency problem in o ainer growing operations is the blank container. o example, if overall germination is low and a i le seed is sown in each container, the number f lank containers will be high, and the cost of a ying these blanks may not be acceptable. In h paper we assume that containers are handled n rays or blocks where individual cells are not e vable. Thus, since resowing is infeasible, l ks must be carried or replanted with excess e lings.

The proportion of blank containers can be e ced by sowing more than one seed in some or l containers. Most published reports of nursery o analyses for container operations compare the ff cts of different types of containers for a i d sowing scheme (Vyse and Rudd 1974; Hallman 97; Colby and Lewis 1973; Tinus and McDonald 97). Bohlin and Hultén (1974) compare different u ery strategies, but a given sowing scheme always specifies a constant number of seeds per container. Space and Balmer (1977) published a computer program for evaluating nursery strategies which differ according to their treatment of blank containers.

The cost of producing a given number of seedlings depends upon the germination and survival rate for the seed lot, the cost of seeds, the cost of sowing, the cost of carrying containers, the cost of replanting blank containers, and the cost of thinning excess seedlings.

A frequent choice for reducing blanks is the sowing of two seeds per container. Because this introduces the need for thinning excess seedlings, it necessarily involves an additional expense that may be less acceptable than the cost of carrying blank containers. If neither type of sowing scheme--single sowings only or multiple sowings only--is adequate, then mixed sowing schemes should be considered. For instance, 30% of the containers could receive three seeds, 20% could receive two seeds, and the remaining 50% could receive one seed. In recent work (Pepper and Barnett 1981a, 1981b) we show that mixed sowing schemes are generally more cost-efficient than the standard constant number approach, and we give a method for choosing an optimal sowing scheme when a priori estimates of costs and overall germination and survival rates are available. For the nursery manager who wishes to use this method we developed a user-oriented, interactive computer program which determines an optimal sowing strategy for producing a required number of seedlings with a specified number of containers (Pepper and Hodge 1981).

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[1] Paper presented at Southern Containerized or t Tree Seedling Conference, Savannah, Georgia, ug t 25-27, 1981.

[2] Authors are Mathematical Statistician and ri ipal Silviculturist, Southern Forest Experi- en Station located at New Orleans, LA 70113, and in ville, LA 71360, respectively.

METHODS

In this paper we assume that sowing is accomplished by a widely used technique employing a vacuum-operated seeder (Carlson 1979). This type of seeder uses a vacuum to hold single seeds over holes in a template. When the vacuum is released the seeds drop into the cavities. If more than one seed per cavity is needed the operation is repeated. A mixed sowing strategy is accomplished by making additional passes over the trays, or by increasing the vacuum so that more than one seed is held to the hole in the template.

The key quantities in a sowing strategy are total number of seeds, predicted number of plantable seedlings before thinning, predicted number of plantable seedlings after each occupied cell is thinned to one seedling, predicted number of excess seedlings, and predicted number of blank containers. These quantities are computed in terms of germination and survival rates and sowing frequencies and the probabilities may be estimated with the binomial formula

$\hat{P}_{ij} = \binom{j}{i}(\hat{p})^{i}(1-\hat{p})^{j-i}$, $i = 0, 1, 2, \ldots, j$; $\hat{p}$ = estimated germination and survival rate and $\hat{P}_{ij}$ = estimated probability of producing i plantable seedlings given that j seeds were sown. In practice no more than 3 seeds per cell are sown so that $i = 0, 1, 2, 3$; $j = 1, 2, 3$.

In practice $\hat{p}$ will often represent an overall average germination and survival rate for a composite of seed lots. Naturally, the reliability of the estimate is influenced by the amount of variation within and among seed lots, but will usually not be quantified because of the lack of estimates for these variables. The assumptions for this model are:

1. The germination of a seed and establishment of the seedling form an independent event that does not affect the chance of success for the other seeds in a container.

2. The probability of success is the same for each seed in a given container.

These conditions may not be completely satisfied in some container operations, but Pepper and Barnett (1981a) showed that the assumptions were not seriously violated in a single--and multiple--sowing experiment with loblolly pine seed. The same study showed that thinning excess longleaf pine seedlings has a negligible effect on the remaining seedlings in a container. Throughout this paper we assume that the binomial model is a satisfactory representation of the germination and survival process and that mortality adjust are unnecessary for seedlings remaining in thi cells.

It is neither realistic nor necessary to identify all costs that might occur in the production of a container-grown seedling. Rather define a function that reflects the penalty wh blanks occur and remedial actions are taken.

As a point of departure we consider the e case of perfect seed and seedling performance 100% germination and establishment. In this ca a single seed is sown in each cell and all see produce seedlings; no thinning is necessary an blanks occur. Thus, the seed-related cost is regarded as a penalty. But in reality blanks occur and we choose a sowing strategy to reduce blanks. The additional number of seeds require and the additional cost of seeds and sowing are considered penalties. The cost of carrying bla and/or replanting blanks is estimated as is the cost for thinning excess seedlings when the see lings thinned are not used for replanting blank

It was assumed that the cost of sowing is same for each seed. This assumption seems logi since the seeder must make a pass over the tray cells for each seed planted per cell.

The cost for thinning was assumed to be th same for each seedling. The validity of this assumption may depend upon the frequency of cel containing excess seedlings. If relatively few must be thinned, the cost per seedling for a gi cell may be influenced by the amount of time sp walking to that cell. On the other hand, if ne all cells contain excess seedlings, walking tim between cells is not a significant variable, an the cost of thinning should be the same for eac seedling. From this it appears that the consta thinning cost assumption will not be erroneous unless there is little thinning to be done. Th the final impact of this potential error on the penalty function should be minimal. The thinni cost applies only to excess seedlings not used replanting blank cells.

The cost of replanting a blank cell consist of the cost of removing an excess seedling from another cell and transplanting it to the blank cell. The mortality of transplanted seedlings i assumed to be negligible.

The cost of carrying a blank cell was defin as the cost of the container plus the cost of th medium. Container costs vary according to the type and the number of times that they can be reused.

The sum of the independent contributions of the cost components described above is the total penalty, including the cost of blanks and the cost of remedial actions to reduce blanks. Our purpose is to present a method for choosing a strategy to minimize the predicted total penalty.

Two options are considered for producing a given number of seedlings:

Option 1. Blank containers are not replanted, but excess seedlings are thinned.

Option 2. Use a sowing strategy for which the predicted number of blanks does not exceed the predicted number of excess seedlings. Remove enough excess seedlings to replant blanks and thin the remaining excess seedlings.

An interactive computer program (CONSOW)[3] written in BASIC was developed to perform these calculations for both Option 1 and Option 2 problems (Pepper and Hodge 1981). As basic input the user provides an estimate of the overall germination and survival rate, an estimate of the cost components described above and the required number of seedlings per cell. For the specified constraints CONSOW produces a complete list of extreme point solutions, each of which is a candidate for optimality. The value of the penalty function is computed for each of these solutions and the one yielding the smallest value corresponds to the optimal sowing strategy. The mathematical derivations upon which this computer program is based has been described in detail (Pepper and Barnett 1981b).

In our work we assumed resources were available to produce the required number of seedlings, and the objective was to choose a sowing strategy to minimize a penalty function or maximize efficiency in some sense. Many nursery managers might formulate the optimization problem in a different manner. An objective might be to produce as many seedlings as possible with limited resources.

These limitations would probably be reflected in the size of the operation and the availability of money. If they could be expressed as linear constraints, the linear programming approach to optimization would be straightforward. A sowing strategy could be chosen to maximize the predicted number of plantable seedlings subject to the appropriate constraints.

We did not attempt to solve this type of problem. Though we were tempted to set an upper bound on the penalty function making it a linear constraint on seedling maximization, we were hesitant to select arbitrary bounds. It appears that a carefully chosen cost function might be useful for expressing limitations on funds in this type of problem.

RESULTS AND CONCLUSIONS

Choosing a sowing strategy for a container operation can be formulated as a linear programming problem. The independent variables are fractions of containers sown with 1, 2, . . . , n seeds. In practice n will generally not exceed 3. Sowing 3 seeds in each container was never an optimal strategy for problems considered in our applications.

When cost components are used to compute coefficients for the independent variables in the penalty function, it is a relatively simple matter to choose values of the independent variables to minimize penalty. In our experience, for a given container sowing problem the range in penalty values (maximum - minimum) over all admissable sowing strategies has been substantial, and this provided evidence that seeking the optimal solution was worthwhile.

Theoretically, it pays to use excess seedlings to replant blanks. Our work shows maximum gains possible using Option 2 in lieu of Option 1. Actual gains depend on the rate of survival of replanted seedlings. If a high rate of survival is possible, Option 2 seems definitely superior to Option 1, unless the cost of replanting blank cells exceeds the sum of the costs of thinning excess seedlings and carrying blank cells.

With a given number of containers, mixed sowing strategies can theoretically produce a fixed number of seedlings more efficiently than the standard sowing strategy (2 seeds sown in each cell). Basically, this means that mixed sowing strategies do a better job of dealing with problems caused by blanks.

Sensitivity analyses indicate that the superiority of mixed sowing strategies is fairly resistant to changes in price components. When seed viability is high, large price changes would be needed to make standard strategies more efficient than mixed strategies, as judged by our penalty function.

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[3] Available from the senior author.

LITERATURE CITED

Bohlin, Henrik and Håkan Hultén.
1974. Single or multiple seedling--An analysis of alternative procedures in producing containerized plants. Res. Note No. 54, 1974, 59 p. Royal College of Forestry, S-10405 Stockholm 50 Sweden.

Carlson, L. W.
1979. Guidelines for rearing containerized conifer seedlings in the Prairie Provinces. Information Report NOR-X-214, 62 p. Canadian Forestry Service, Northern Forest Research Centre, Edmonton, Alberta.

Colby, Marilyn K. and Gordon D. Lewis.
1973. Economics of containerized conifer seedlings. USDA For. Serv. Res. Pap. RM-108, 7 p. Rocky Mont. For. Range Exp. Stn., Fort Collins, CO.

Hallman, Richard G.
1974. Cost of raising containerized trees in the United States Part A--A computer program. In Proc. of the North American Containerized Forest Tree Seedling Symposium. Denver, Colorado, August 26-29, 1974. Great Plains Agric. Counc. Pub. No. 68:412-427.

Pepper, W. D. and J. P. Barnett.
1981a. Predicting seed germination and seedling establishment in containers. Can. J. For. Res. (In press)

Pepper, W. D. and J. P. Barnett.
1981b. Choosing sowing strategies for containerized seedling operations. Can. J. For. Res. (In press)

Pepper, W. D. and W. D. Hodge.
1981. A computer program for choosing sowing strategies for containerized seedling operations. U.S. Dep. Agric. For. Serv. Gen. Tech. Report, South. For. Exp. Stn., New Orleans, La. (In press)

Space, James C. and William E. Balmer.
1977. Minimum cost calculation for container planting. 18 p. U.S. Dep. Agric. For. Serv., Southeast. Area State Priv. For.

Tinus, Richard W. and Stephen E. McDonald.
1979. How to grow tree seedlings in containers in greenhouses. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. RM-60, 256 p. Rocky Mont. For. Range Exp. Stn., Fort Collins, CO.

Vyse, A. H. and J. D. Rudd.
1974. Sowing rules for container nurseries. In Proc. of the North American Containeriz Forest Tree Seedling Symposium. Denver, Colorado, August 26-29, 1974. Great Plain Agric. Counc. Pub. No. 68:164-169.

GERMINATION CHARACTERISTICS OF SOUTHERN PINE AS INFLUENCED BY TEMPERATURE[1]

J. R. Dunlap[2] and J. P. Barnett[3]

Abstract.--The germination patterns of loblolly (*Pinus taeda*), shortleaf (*P. echinata*) and longleaf (*P. palustris*) were determined under the influence of temperature regimes which alternated between 22°C and two less favorable temperatures, 13°C and 35°C. The germination of loblolly and shortleaf were accelerated with exposure to increasing temperature regimes. The rates of longleaf germination were not significantly changed across any temperature regime; however, uniformity and final germination were optimized by periodic exposure to 13°C. The identification and practical use of temperature regimes to manipulate germination patterns were discussed relative to greenhouse production of pine seedling crops.

INTRODUCTION

The yield of pine seedling crops can be sub- ially influenced by seed germination patterns. germination results in low yields of seedlings nit growing area. Slow germination can yield p of established seedlings which display wide tion in size and acceptable quality (personal vation). Consequently, seed germination pat- represent a major variable in the success- roduction of a uniform seedling crop under olled or natural environments.

Production of containerized seedlings under house conditions offers the opportunity for al control of several environmental para- s not afforded an outdoor growing system. One ose environmental parameters with a profound t on seed germination is temperature ecker, 1977; Koller, 1972). Barnett (1979) cLemore (1966, 1969) have both shown that the nation of loblolly pine (*P. taeda*) was inhib- at temperatures below 20°C and above 30°C. ate of germination was also delayed as either me was approached (Barnett, 1977).[4] Similar experiments were conducted with slash (*P. elliottii* var. *elliottii*), shortleaf (*P. echinata*) and longleaf (*P. palustris*) pine (Barnett, 1977[5]; 1979). Again, dramatic reductions in the rate and final germination took place when treatments were incubated outside a temperature range of 20° to 30°C. The germination of longleaf pine was optimum at 24°C, a temperature slightly less than optimum for the other species tested.

All of the previously described studies were conducted at constant temperatures. Current greenhouse production systems lack total control over temperature as reflected by alternation between daily maxima and minima. The germination patterns of many plant species have been shown to change substantially with the shift from constant to cycling temperature regimes (Heydecker, 1977). Consequently, the germination patterns of southern pine species described by McLemore (1965, 1969) and Barnett (1979) in response to constant temperatures may be quite different under a cycling regime.

The following study was initiated to determine the response of longleaf, shortleaf, and loblolly pine seed to alternating temperatures during germination. This information would provide guidelines for optimizing germination conditions within a greenhouse production system and subsequently enhancing crop yields.

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[1] Paper presented at Southern Containerized t Tree Seedling Conference, Savannah, Georgia, t 25-27, 1981.

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[3] Principal Silviculturist, USDA - Forest ce, Southern Forest Experiment Station, ille, Louisiana 71360.

[4] Barnett, J. P. 1977. Temperature effects rmination of southern pine seeds. USDA For. Res. Rep. SO-1102-1.123, 21 p.

[5] Ibid.

MATERIALS AND METHODS

Three species of southern pine were selected for use in this study. Orchard sources of loblolly (*P. taeda*) and shortleaf (*P. echinata*) seed were supplied by Weyerhaeuser and the Southern Forest Experiment Station, respectively. Both a southern and northern geographic source of each species were collected. A third species, longleaf (*P. palustris*) was supplied from a heterogenous field source collected by the Southern Forest Experiment Station. Consequently, five distinct seed samples encompassing several species and geographical differences were tested.

Seed Preparation

All seed samples were imbibed in distilled water for 24 hours prior to stratification or germination. The loblolly and shortleaf samples were stratified at 4°C for 40 days; longleaf seeds were not stratified. All seed samples were germinated simultaneously in 10 x 10 cm plastic boxes on Kimpak paper moistened with 35 ml of distilled water and fitted with plastic lids. Tests were conducted with three 50-seed subsamples from each major seed source.

Germination Conditions

All species and respective sources were tested under seven different temperature regimes (Fig. 1). The temperatures used to generate this array of regimes were 13°C, 22°C, and 35°C. Each regime was created by alternating between 13°C and 22°C or 22°C and 35°C within a 24-hour time interval. The stress level was varied by exposing seed for 8, 10, or 12 hours to the less favorable temperatures, 13°C and 35°C. One exception was the constant 22°C treatment considered to be optimum for germination which represented a point of comparison for the less than optimal regimes (Anon., 1970). A 12-hour photoperiod was superimposed on each temperature regime (Fig. 1). All germination treatments were imposed to within ± 0.5°C using growth chambers with programmable temperatures and photoperiod.

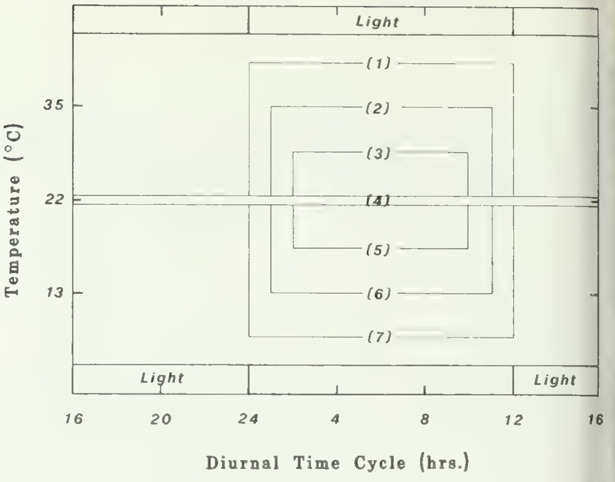


Figure 1.--Treatments used in screening seed responses to different temperature regimes. Sol lines indicate deviation above (1,2,3) or belo (5,6,7) constant 22°C (4) relative to time wit in a 24-hour cycle. Light exposures associate with treatments 1,2,3 and 4 are indicated on t upper edge of the figure; while treatments 5,6, and 7 were represented on the lower portion.

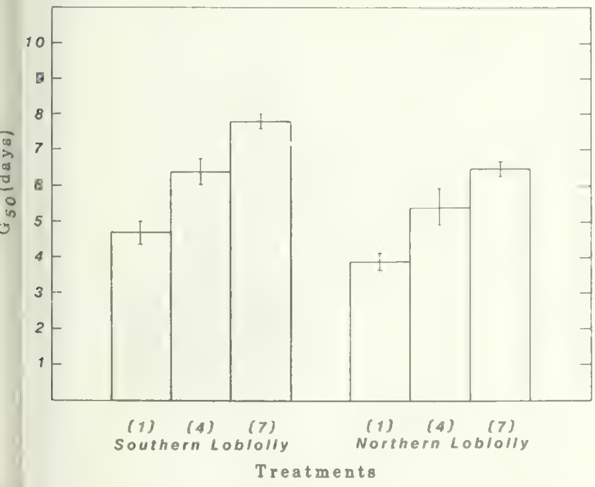
Data Collection and Analysis

Seeds within each treatment were inspected every two days. A seed was considered germinate when the radical had visibly initiated geotropic curvature. The rate of germination (G_{50}) was determined for each treatment by measuring the days from sowing required to achieve 50% of the maximum potential germination. The rate of germinati determined in this manner provided a means of comparing relative germination potentials among the various treatments. Mean rates and their respect standard errors (SE) were calculated for each treatment.

RESULTS AND DISCUSSION

Temperatures during a 24-hour day were altern ed between 22°C and less favorable temperatures f germination, 13°C and 35°C (Fig. 1). The g mination results from all treatments indicated th t a 12-hour exposure to either temperature e reme elicited the greatest treatment response. C sequently, only data from treatment 1 (12 hours a 35°C) and 7 (12 hours at 13°C) were used in the s dy evaluation. Responses to treatment 1 and 7 we e compared to the more favorable temperature re resented by treatment 4 (constant 22°C).

The reductions in germination previously rep ted (Barnett, 1979) in response to the tempera re extremes examined in this study, 13°C and 3 C, were not observed when alternated with a more m erate temperature, 22°C. The germination of lo lolly seed was actually accelerated at the h her temperature regime (treatment 1) in contrast to germination taking place under less severe co ditions present in treatment 4 (Fig. 2). Seed in ubated under temperatures alternating between 3 C and 22°C (treatment 1) achieved 50% germinat n almost 3 days before seed incubated under the lo er regime in treatment 7. The southern source ge minated more slowly than the northern source as in icated by an additional 1 to 1.5 days required to achieve 50% germination (Fig. 2). This delay in the rate of germination could have been attribu ed to the source difference (Villiers, 1972). Ho ever, the limited number of sources screened in th s particular study did not permit such an in erpretation. Additional investigations have sh wn that the southern source was expressing a de per level of dormancy than the northern source wh ch explained the slower germination with equal st atification time (unpublished data). The final ge mination of either loblolly seed source was un ffected by any of the temperature regimes. The ge eral response of loblolly seed to the various te perature regimes was a relatively constant in rease in the speed of germination (G_{50}) with in reasing temperatures.



Fi ure 2.--Rate of germination (avg. $G_{50} \pm$ SE) or a southern and northern source of loblolly ine incubated under temperature regimes 1, 4, nd 7.

The germination pattern displayed by both shortleaf sources paralleled the data from similar treatments using loblolly seed. The rate of germination was slower at the lower temperature regime, treatment 7 (Fig. 3). Both sources of shortleaf required approximately 6 days to achieve 50% germination at the lower temperature regime. The same sources incubated at the higher temperature regime, treatment 1, reached 50% germination within approximately 3 days after sowing. The final germination was not affected by any of the treatments.

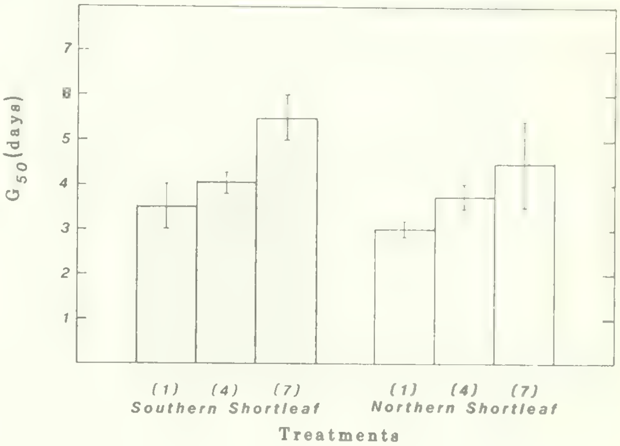


Figure 3.--Rate of germination (avg. $G_{50} \pm$ SE) for a southern and northern source of shortleaf pine incubated under temperature regimes 1,4 and 7.

The germination pattern exhibited by longleaf seed in response to the various treatments was quite different from patterns observed in loblolly and shortleaf. There was a tendency for germination rates (G_{50}) to decrease as the incubation temperature for longleaf seed was increased (Fig. 4). In spite of very little change in the rate of germination, a relatively large increase in the standard error of the mean G_{50} value was observed at higher temperatures. This increase in variation around the mean germination rate reflected a more erratic germination pattern typical of seed incubated under stressful conditions (Barnett, 1977[6/]; Heydecker, 1977). In contrast to only slight changes in germination rates, the final germination percentages after incubation for 28 days were significantly reduced by treatment 1 (Fig. 4). Germination was decreased from a maximum of 90% in treatment 7 (12 hours at 13°C) to 50% in treatment 1 (12 hours at 35°C). Consequently, longleaf responded more favorably to lower temperatures than loblolly and shortleaf.

[6/] Ibid.

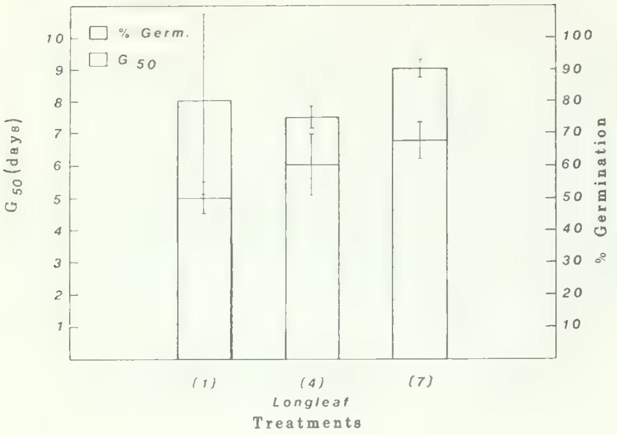


Figure 4.--Rate (avg. $G_{50} \pm$ SE) and final (avg. % ± SE of total population 28 days after sowing) for a field collected source of longleaf pine incubated under temperature regimes 1,4 and 7.

An earlier study (Barnett, 1979) showed that constant exposure to 35°C and 13°C was detrimental to the germination of loblolly, shortleaf and longleaf pine seeds. Our more recent study has proven that these same temperature extremes were quite acceptable if alternated with less severe temperatures such as 22°C. The alternation of the extremes, 35°C and 13°C, with a more optimal temperature (22°C) actually improved germination patterns relative to incubation at constant 22°C. However, the response varied according to species.

APPLICATION

In the development of a production system for loblolly, shortleaf and longleaf, the grower will require at least two different temperature regimes. This might be accomplished by taking advantage of seasonal temperatures and starting each species during periods when natural temperatures would aid in achieving some optimum regime within the greenhouse. Simultaneous growing of all three species is slightly more complex with regard to germination. However, the grower could take advantage of seasonal temperatures and start the species most suitable for the natural temperature regime outdoors. Species less suitable for germination would be started in the greenhouse under a controlled temperature regime. This procedure would maximize the germination potential of all three species examined in this study. Subsequent growth would take place under controlled conditions using a temperature regime which optimized the simultaneous growth of all three species.

LITERATURE CITED

Anon.
1970. Rules for testing seed. Proc. Assoc. O
Seed Anal. 60: 74.
Barnett, J. P.
1979. Germination temperatures for container culture of southern pines. S. J. App. For. 3: 13-14.
Heydecker, W.
1977. Stress and seed germination. In: A. A. Kahn, ed., The Physiology and Biochemistry o
Seed Dormancy and Germination., Elsevier/ North-Holland Press, New York. pp. 263-270.
Koller, D.
1972. Environmental control of seed germinati
In: T. T. Kozlowski, ed., Seed Biology, Vol. II, Academic Press, New York. pp. 15-35.
McLemore, B. F.
1966. Temperature effects on dormancy and germination of loblolly pine seed. For. Sci. 12
284-289.
McLemore, B. F.
1969. Long stratification hastens germination
loblolly pine seed at low temperatures. J. For. 67: 419-420.
Villiers, T. A.
1972. Seed dormancy. In: T. T. Kozlowski, ed.
Seed Biology, Vol. II, Academic Press, New York. pp. 275-276.

PRODUCING PLANTABLE SEEDLINGS[1]

James P. Barnett[2]

echniques used in bare-root and containerized eedling production. Container-growing regimes equire closer daily control because the volume of edium available to the seedling is small and the nvironmental conditions present in most facilities an result in the rapid development of disease or ther problems.

There are numerous differences in growing echniques used in bare-root and containerized eedling production. Container-growing regimes equire closer daily control because the volume of edium available to the seedling is small and the nvironmental conditions present in most facilities an result in the rapid development of disease or ther problems.

One critical aspect of starting up a ontainer-growing facility that has not been ddressed by our speakers is choosing a qualified grower" or greenhouse manager. Unfortunately, orestry school graduates are not well trained o grow seedlings under greenhouse conditions and orticulturists are generally not familiar with roducing conifers. Therefore, the assignment as reenhouse manager must be made more on interest nd potential than current knowledge and ability.

An important element in developing expertise is to give an individual the responsibility and the time to learn the system. Make the position his first responsibility, even though you may have a small operation. Daily inspection and time to live with the seedlings and learn biological responses specific for the species and facilities is essential. If the manager is observant, the specifics of greenhouse culture will develop quickly. By all means, learn from others' experience. Many aspects of seedling culture for the southern pines have been developed to the point that some guidelines are available. However, there is considerable variation in seedling response related to container systems, species, season, and facilities.

In the near future, we hope to publish a "Handbook for growing containerized southern pines." While this will not provide final answers to all questions of rearing containerized seedlings, it will provide assistance to those beginning new container-growing operations.

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[1] Presented at Southern Containerized orest Tree Seedling Conference, Savannah, Georgia, ugust 25-27, 1981.

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RELATING SEEDLING MORPHOLOGY TO FIELD PERFORMANCE OF CONTAINERIZED SOUTHERN PINES [1]

John M. McGilvray
and
James P. Barnett[2]

Abstract.--Many initial morphological characteristics are related to field performance of container-grown southern pines. Of these, only seedling height at the time of outplanting has consistently shown a relationship to future field performance. Containerized seedlings appear to have different requirements for outplanting than bare-root seedlings. Although the data are preliminary, some suggestions for containerized loblolly pines are presented.

INTRODUCTION

Containerized seedlings of low vigor or poor uality can survive if soil moisture and other vironmental conditions at the time of outplanting re near optimal. However, when less favorable con-itions are met soon after outplanting, the morpho-gical and physiological conditions of the out-lanted seedlings are closely related to their bility to survive. A number of workers have noted hat seedlings that are large and woody survive and row better than smaller seedlings on difficult ites or where competition is severe (Iverson and ewton 1980, Davidson and Sowa 1974, Walker and hnson 1980, Barnett 1974). Southern pine seed-ings are usually large enough at 12 to 14 weeks o perform well in the field. A few more weeks of rowth may be desired when planting is on more diffi-ult sites. Age alone, however, is not a reliable riterion of when to plant, because seedling develop-ent varies greatly by season, facility, and cultural reatment.

Almost 30 years ago, Wakeley (1954) estab-ished a grading system based on morphology for re-root southern pine seedlings. This grading stem, based primarily on height, diameter, and ture of the stem, is still the best available. wever, because there are basic differences in age, evelopment, and cultural regimes between bare-root d container-grown seedlings, grades established r bare-root stock may not be the same as for ose grown in containers. Over the past several years we have tried to determine which morphological characteristics of containerized seedlings relate directly to field performance. Data obtained from four preliminary studies, referred to as Studies 1, 2, 3, and 4 throughout this paper, are discussed.

CHARACTERISTICS EVALUATED

A variety of seedling characteristics have been directly related to field performance at one time or another. These include: shoot/root ratio, height, stem diameter, dry weight, chlorophyll content, secondary needles, and mycorrhizal development. The value of these measurements as indicators of performance for container-grown seedlings varies greatly.

Shoot/Root Ratios

Seedlings usually have been reared with the view that a seedling with a shoot/root ratio between 1 and 2 would perform better after planting (Ferdina 1972, Wakeley 1954). Recent work by Walker and Johnson (1980) with northern species of spruce and pine shows that much higher shoot/root ratios may be better for container-grown seedlings. Regression analyses of their data indicate that the weight obtained 1 year after planting is proportional to initial seedling weight and shoot/root ratio; larger seedlings with shoot/root ratios of up to 7.4 had significantly greater weight increases than smaller seedlings with ratios of 2.0. A similar relationship was found with the southern pines when shoot/root ratios were related to seedling height (fig. 1).

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[1] Paper presented at Southern Containerized rest Tree Seedling Conference, Savannah, Georgia, gust 25-27, 1981.

[2] Biological Laboratory Technician and incipal Silviculturist, respectively, USDA-rest Service, Southern Forest Experiment Station, neville, LA 71360.

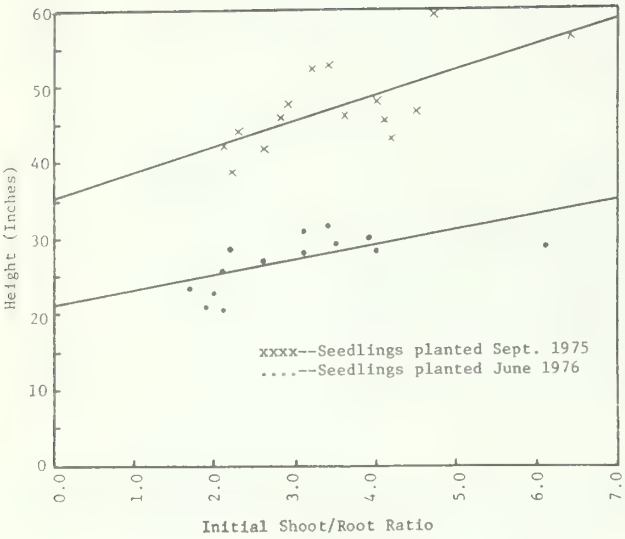

Figure 1.--Initial shoot/root ratio and seedling height relationships 2-1/2 and 3-1/4 years after outplanting (Study 1), based on two separate outplantings of loblolly pines.

It is apparent from the data shown in figure 1 that a so-called "balanced" seedling is not necessary or even desirable with container-grown plants. In our work with container-grown seedlings, higher shoot/root ratios are more a function of larger shoots than variations in root size. Therefore, we have concluded that shoot/root ratio is generally not a meaningful criterion when evaluating containerized southern pine seedlings.

Chlorophyll Content

Chlorophyll content in seedling needles has been shown to give an estimate of stock quality (Sutton 1980). In one of our studies, the chlorophyll content of the needles at planting was correlated to the height of the pine seedlings 1, 2, and 3 years later (Table 1). In this particular study, high chlorophyll content related well to seedling vigor. However, different nutritional regimes were practiced during the greenhouse growing period, and thus differences in seedling quality may have been due to a close relationship between chlorophyll and nitrogen contents, Chlorophyll is generally a nonspecific indicator that is influenced by many factors. When seedlings are grown with abundant nutrients, chlorophyll content will probably not be closely related to field performance.

Mycorrhizae

The visible presence of mycorrhizae on slash and loblolly pine seedlings indicates increased survival of nursery stock (Jorgensen and Shoulder 1967, Shoulders and Jorgensen 1969). The amount of mycorrhizae can have a significant effect on survival and growth of southern pine nursery stock.

The need for mycorrhizal development on container-grown seedlings is probably not as grea as with nursery-grown plants because the root system remains intact when planted and initial stress conditions are less. Shortleaf pine seedlings grown in containers and inoculated with *Pisolithus tinctorius* and *Thelephora terrestris* mycorrhizae did not survive or grow better than those that were not inoculated when outplanted on dry sites in the Ouachita Mountains of Arkansas (Ruehle et al. 1981). In fact, performance of inoculated seedlings with over 50 percent root infection was no better than for seedlings grown under a high fertility regime where only 16 percent of the roots showed mycorrhizae.

This apparent less critical need for mycorrh on containerized seedlings is fortunate because the high-fertility regimes generally used in production seem to inhibit mycorrhizal development. The presence of mycorrhizae on root systems becom more important as the planting sites become more difficult. Goodwin (1980) reported that inoculation with *Pisolithus* increased field performanc of container-grown loblolly and Virginia pine on adverse borrow site.

Secondary Needles

The development of fascicle or secondary needles is one criteria used by Wakeley (1954) in his seedling grading system for nursery stock. Our tests with container-grown southern pines sho that the presence of secondary needles is an important indicator of seedling development (Barn 1980). Secondary needles develop when the stem becomes woody and stiff. This condition represent a stage when the seedlings become more hardy and less susceptible to cold and drought damage. Thus seedlings that have secondary needles are mor vigorous than those that have not yet reached thi stage of development.

Stem Diameter

Stem diameter was shown to be a characteristi closely related to seedling development of loblol and shortleaf pine in Study 1 (Table 1). Study 2 confirmed the relationship of stem diameter of loblolly pine to seedling growth after outplanting (Table 2). However, diameter was not consistentl related to field survival. For example, longleaf stem diameters were correlated with survival in Study 2 (Table 2) but not in Study 1 (Table 1).

ble 1.--Summary of correlation coefficients relating initial seedling development to field performance (Study 1). Seedlings outplanted June 22, 1976

Seedling characteristics	Survival			Height		
	Feb. 1977	Feb. 1978	Feb. 1979	Feb. 1977	Feb. 1978	Feb. 1979
			Loblolly Pine[1]			
ight	0.021	0.238	0.324	0.972*	0.743*	0.738*
ameter	.168	.361	.455	.913*	.819*	.833*
ot weight	- .345	- .259	- .339	- .078	- .225	- .259
em weight	.049	.294	.315	.870*	.646*	.655*
lorophyll	.235	.418	.595*	.771*	.915*	.899*
			Longleaf Pine[2]			
ameter	.079	.046	.020	- .106	- .112	- .162
ot weight	.534*	.522*	.479	- .396	- .435	- .431
em weight	- .252	.296	.176	.548*	.590*	.555*
lorophyll	- .418	- .566*	.443	.866*	.810*	.798*
			Shortleaf Pine			
ight	.052	.147	.283	.929*	.829*	.784*
ameter	- .142	- .058	.099	.761*	.760*	.687*
ot weight	.170	.157	.182	- .061	- .021	- .057
em weight	.030	.128	.249	.773*	.743*	.666*
lorophyll	.281	.193	.302	.913*	.861*	.832*

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[1] An asterisk represents statistical significance at the 0.05 level.

[2] Longleaf growth was evaluated by measuring root-collar diameter (inches) rather than height.

ble 2.--Summary of correlation coefficients relating initial seedling development to field performance (Study 2). Seedlings outplanted June 27, 1977

Seedling characteristics	Survival			Height	
	March 1978	Feb. 1979	Jan. 1980	Feb. 1979	Jan. 1980
			Loblolly Pine[1]		
ight	0.441	0.497*	0.481	0.430	0.615*
ameter	.475	.532*	.522*	.496	.601*
ot weight	.519*	.527*	.514*	.368	.476
em weight	.417	.470	.460	.432	.518*
			Longleaf Pine[2]		
ameter	.320	.317	.346	.670*	.510*
ot weight	.534*	.514*	.495	.196	.222
em weight	.131	.149	.207	.292	.384

---

[1] An asterisk represents statistical significance at the 0.05 level.

[2] Longleaf growth was evaluated by measuring root-collar diameter (inches) rather than height.

These studies indicate that stem diameter, an easily measured characteristic, is indicative of seedling growth, if not survival. The combinations of stem diameter with other easy measureable properties should improve predictions of field performance.

Seedling Heights

The height of a seedling when outplanted is generally a good indicator of subsequent field performance (Walker and Johnson 1980, Iverson and Newton 1980). Our studies with container-grown southern pines confirm this observation (Tables 1 and 2). Not only is height at time of outplanting closely related to subsequent heights, but it is also correlated to incremental growth for a number of years (Table 3). How long this relationship will hold is open to question. Blair and Cech's (1974) work with slash pine nursery stock has shown that Wakeley's Grade 1 and 2 seedlings produced significantly more volume after 13 years than Grade 3 seedlings (fig. 2). In Wakeley's morphological grades, height is a major criterion, with the lower grades exhibiting greater seedling height. Similar results have been published for loblolly and slash pine after 30 years (Wakeley 1969).

Heights and diameters should both be considered when developing predictions of field performance. If containerized seedlings are grown at high seedling densities, heights may be about the same as when grown at lower densities, but stem diameters of the seedlings grown at the lower densities will be larger, and they have been shown to perform better in the field (Barnett 1980).

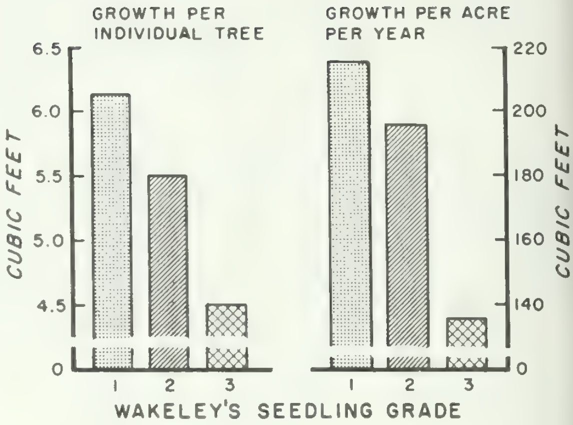

Figure 2.--Volume performance of graded slash pi seedlings after 13 growing seasons (Blair and Cech 1974).

Table 3.--Correlation coefficients of morphological characteristics of loblolly pine seedlings with heights and growth in the field (Study 3). Outplanted February 1976

Seedling characteristics	Height			Growth/year		
	1 year	2 years	3 years	1st year	2nd year	3rd year
Height	.864*[1]	.814*	.829*	.490*	.770*	.840*
Stem diameter	.899*	.864*	.832*	.579*	.826*	.842*
Root weight	.700*	.641*	.628*	.386*	.594*	.582*
Stem weight	.890*	.837*	.847*	.536*	.790*	.846*

[1] An asterisk represents statistical significance at the 0.05 level.

Dry Weights

Dry weights of seedling stems at the time of outplanting were correlated with heights in the field over several years (Tables 1, 2, and 3), but were not closely related to survival. Correlations of dry weights of roots at outplanting to survival in most instances did not occur consistently. Only in Study 1 was root weight related to field survival of longleaf pine (Table 1). In Study 2, correlations between root weight and survival occurred with both loblolly and longleaf pine (Table 2). In this study, initial root weights did not relate to seedling height increases. Correlations of both height and growth to dry weights did occur with loblolly pine in Study 3 (Table 3). Differences in response among studies seem related to environmental conditions at or shortly after planting.

SUGGESTED CHARACTERISTICS FOR LOBLOLLY PINE

There is an insufficient amount of data at this time to specify the optimum characteristics of containerized southern pine seedlings to obtain maximum survival and growth when outplanted. Our best information is for loblolly pine, but these data are from studies not designed to provide predictive equations relating initial seedling quality to field performance. However, these data are probably the best available for the southern pines and will give some feel for the relationship between morphology and growth.

There is considerable difference in the ease and reliability of measuring the various seedling characteristics that relate to field performance. Characteristics such as chlorophyll content, dry weights, and shoot/root ratios are not as easy to determine as are seedling heights or diameters. Our results indicate that simplification of measurements may be feasible. For example, seedling stem diameter at the time of outplanting is closely related to initial height (fig. 3). This initial stem diameter is also related to seedling heights in the field 2 and 3 years after planting (fig. 4). Correlations of stem dry weight with height after outplanting are also significant (fig. 5). These correlations are similar to those that relate initial height to field heights 1, 2, or 3 years later (fig. 6).

As long as the type of container and cultural treatment remain constant and provide for good quality seedlings, height at the time of outplanting seems to be the best single morphological indicator of field performance. It is easily measured and is related to field performance. Other visual criteria, such as presence of secondary needles and woody tissue, should also be taken into consideration.

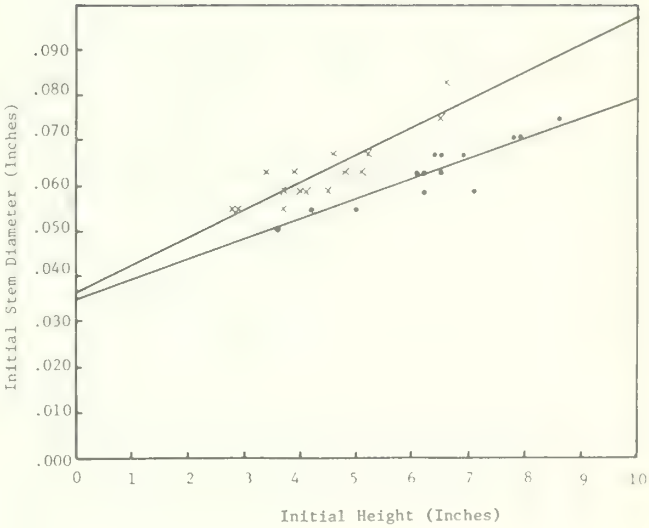

Figure 3.--Initial height and stem diameter relationship for loblolly pine seedlings (Study 1) based on two separate outplantings.

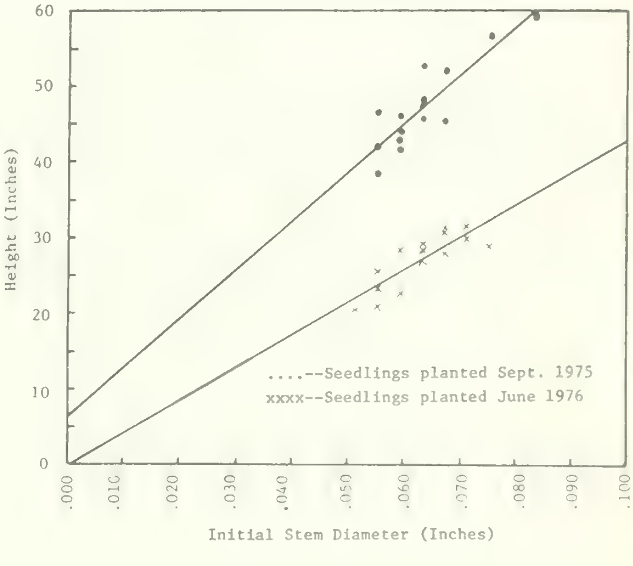

Figure 4.--Initial stem diameter and height relationships for loblolly pine seedlings 2-1/2 and 3-1/4 years after outplanting (Study 1) based on two separate outplantings.

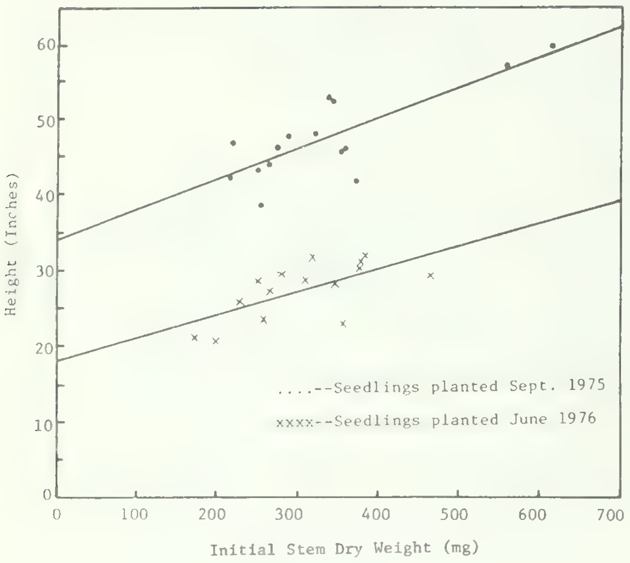

Figure 5.--Initial dry weight and seedling height relationship for loblolly pine seedlings 2-1/2 and 3-1/4 years later (Study 1) based on two separate outplantings.

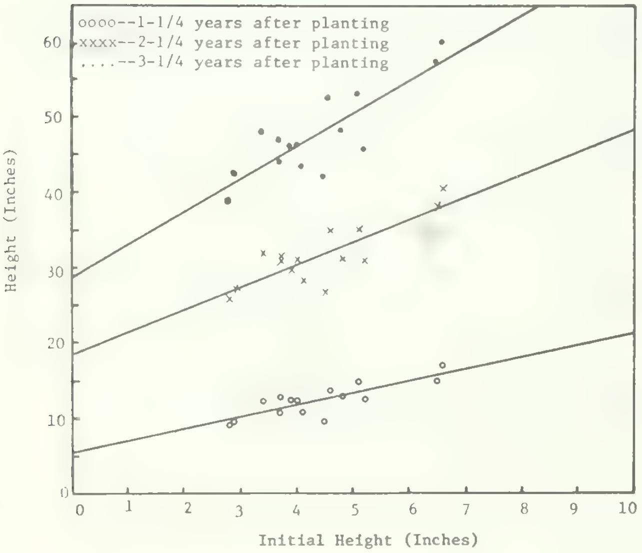

Figure 6.--Comparison of initial seedling height of loblolly pine seedlings to heights at 1-1/4, 2-1/4 and 3-1/4 years (Study 1).

The correlations of seedling diameters, stem weights, and heights at the time of outplanting a indicate that, within the range of the data, fiel performance improves as size at the time of outpl ing increases. Not only are seedling heights gre in the field after several years, but yearly grow several years after outplanting is affected (fig.

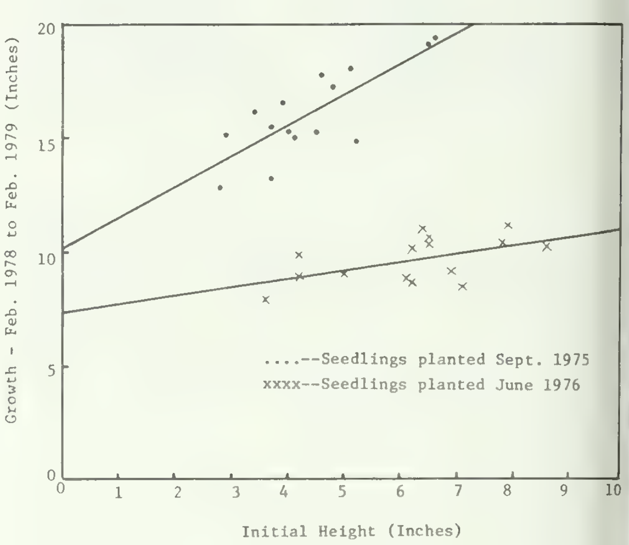

Figure 7.--Relationship between initial height an growth over a 1-year period for loblolly pine seedlings (Study 1) based on two outplantings.

This indicates that larger seedlings provide better field performance. However, these results reflect a limited range of initial seedling sizes from about 3 to less than 9 inches in height. Al it is expected that a point exists after which la seedlings do not result in greater field growth. Data from Study 4, where there were larger initia seedling sizes (7 to 13 inches), show that in thi larger size range no correlation occurs with fiel heights (fig. 8). Thus, biologically as well as economically, there are practical limitations to how large seedlings should be at outplanting.

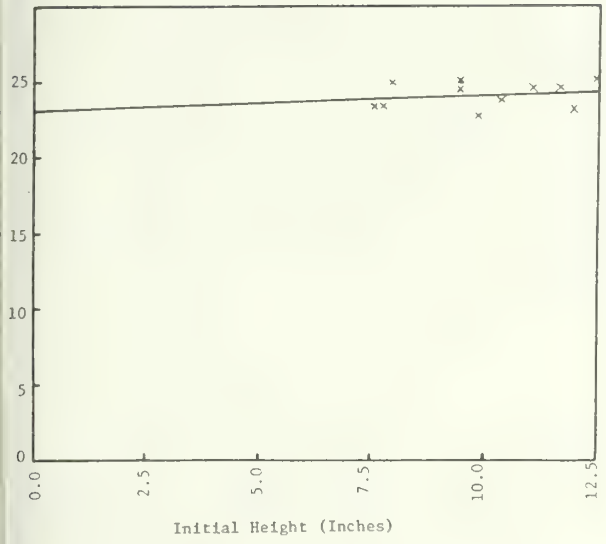

Figure 8.--Initial height and future height relationships for loblolly pine seedlings 1-1/2 years after outplanting (Study 4).

CONCLUSIONS

These data are preliminary and cannot provide specific recommendations for grading container-grown seedlings. However, they do indicate some of the relationships that exist among different seedling characteristics and field performance. In the studies reported here, survival was consistently high and therefore allowed only limited evidences of varying performance with initial seedling morphology.

A number of seedling characteristics were closely related to growth in the field. Of these, height was directly related to field performance and is the most easily measured. A combination of heights and other characteristics is probably desirable when seedlings are evaluated after being grown under varying container, cultural, and environmental conditions. For loblolly pine seedlings, heights of 6 to 8 inches, presence of secondary needles and woody tissue, and diameters of 0.06 to 0.10 inches at the time of outplanting should result in excellent survival and growth.

LITERATURE CITED

Barnett, James P.
1974. Tube lengths, site treatments, and seedling ages affect survival and growth of containerized southern pine seedlings. U. S. Dep. Agric. For. Serv. Res. Note SO-174, 3 p. South. For. Exp. Stn., New Orleans, La.

Barnett, James P.
1980. Density and age affect performance of containerized loblolly pine seedlings. U. S. Dep. Agric. For. Serv. Res. Note SO-256, 5 p. South. For. Exp. Stn., New Orleans, La.

Blair, Roger, and Franklin Cech.
1974. Morphological seedling grades compared after thirteen growing seasons. U. S. Dep. Agric. For. Serv., Tree Planters' Notes 25(1):5-7.

Davidson, Walter H., and Edward H. Sowa.
1974. Container-grown seedlings show potential for afforestation of Pennsylvania coal-mine spoils. U. S. Dep. Agric. For. Serv., Tree Planters' Notes 25(4):6-9.

Ferdinand, I. S.
1972. Container planting program at North Western Pulp and Power Ltd. In Proc. of a workshop on container planting in Canada. Environ. Canada, Canadian For. Serv., Dir. Program Coord. Inform. Rep. DPC-X-2, p. 21-25.

Goodwin, O. C.
1980. Survival and growth of loblolly and Virginia pine seedlings colonized with *Pisolithus tinctorius* on a borrow site in North Carolina. North Carolina Forest Service Forestry Note 44, 5 p.

Iverson, R. D., and Michael Newton.
1980. Large Douglas-fir seedlings perform best on Oregon coastal sites. Int. Pap. Co., Western For. Res. Center Tech. Note 55, 9 p.

Jorgensen, J. R., and Eugene Shoulders.
1967. Mycorrhizal root development vital to survival of slash pine nursery stock. U. S. Dep. Agric. For. Serv., Tree Planters' Notes 18(2): 7-11.

Ruehle, John L., Donald H. Marx, James P. Barnett, and William H. Pawuk.
1981. Survival and growth of container-grown and bare-root shortleaf pine seedlings with *Pisolithus* and *Thelephora* ectomycorrhizae. South. J. Applied For. 5:20-24.

Shoulders, Eugene, and J. R. Jorgensen.
1969. Mycorrhizae increases field survival of planted loblolly pine. U. S. Dep. Agric. For. Serv., Tree Planters' Notes 20(1):14-17.

Sutton, R. F.
1980. Techniques for evaluating planting stock quality. International Union of Forestry Research Organizations (IUFRO Workshop, New Zealand August 1979). For. Chron. 56:116-120.

Wakeley, P. C.
1954. Planting the southern pines. U. S. Dep. Agric. For. Serv. Agric. Monog. 18, 233 p.

Wakeley, P. C.
1969. Results of southern pine planting experiments established in the middle Twenties. J. For. 67:237-241.

Walker, N. R., and H. J. Johnson.
1980. Containerized conifer seedling field performance in Alberta and the Northwest Territories. Canad. Forest Serv., Northern Res. Centre Inform. Rept. NOR-X-218, 32 p.

DISEASES OF CONTAINER-GROWN SOUTHERN PINE SEEDLINGS AND THEIR CONTROL[1]

William H. Pawuk[2]

Abstract.--Seed and soilborne diseases caused by *Fusarium* sp. are the most commonly observed diseases in container culture. Airborne diseases are of minor importance. Sound cultural practices and use of fungicides can effectively control disease problems. Fungicides can be chosen that do not inhibit seed germination or ectomycorrhizal development.

INTRODUCTION

Pathogens that cause diseases of southern ne seedlings in bare-root nurseries can cause similar diseases when seedlings are container-grown. Fortunately, not all diseases found in bare-root nurseries have been problems in container seedling culture. The greenhouse environment in ich most container seedlings are grown, differs greatly from the bare-root nursery. Consequently, disease development in container nurseries may be more rapid and intensive. Also, the relatively high cost of container seedlings makes disease loss more serious on a seedling-per-seedling basis than i bare-root nurseries.

While the greenhouse environment can create problems, the nursery manager can control the environment much more than when seedlings are grown outside. He can regulate temperature, humidity, soil moisture, and soil fertility to a great extent. Pesticides can be applied effectively to control diseases and insects.

To control disease losses, a thorough understanding of the pathogens and the conditions necessary for infection is essential. This paper discusses the diseases that have been observed in container-grown southern pine seedlings and suggests methods of control.

SEEDBORNE DISEASES

In the past, seed fungi on sound southern pine seeds have not been considered a problem because most observations indicated the fungi were saprophytic and did not affect germination (Belcher and Waldrip 1972). With the advent of container culture it has become apparent that seedborne fungi can be important causes of seedling mortality. Pawuk and Barnett (1974) associated *Fusarium* infection of container-grown longleaf pine (*Pinus palustris* Mill.) seedlings with retention of infested seedcoats. Cotyledons become infected and the disease spreads to the stem, resulting in mortality. Further studies showed that five species of *Fusarium* that were cultured from longleaf pine seed were pathogenic on longleaf pine seedlings (Pawuk 1978). Mason and Van Arsdel (1978) discovered *Fusarium moniliforme* in abundance on loblolly pine (*P. taeda* L.) seed from Texas seed orchards. It consistently caused top infection damping-off in inoculation trials.

To determine the extent of *Fusarium* infestation on southern pine seed, I sampled 100 seeds from each of 10 seed lots of longleaf, loblolly, slash (*P. elliottii* Engelm.), and shortleaf pine (*P. echinata* Mill.).

All seed lots were infested (Table 1). Slash pine seed was most heavily infested (90.6%), shortleaf (82.5%) and loblolly (78.8%) intermediate, and longleaf the least infested (53.9%). Although longleaf is least infested, disease losses are usually greater in longleaf, perhaps owing to longer retention of seedcoats and its growth habit.

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[1] Paper presented at Southern Containerized Forest Tree Seedling Conference, Savannah, Georgia, August 25-27, 1981.

[2] Plant Pathologist, Stikine Area, Tongass N.F., Box 309, Petersburg, AK 99833. (Research conducted while assigned to Southern Forest Experiment Station, Pineville, LA.)

Table 1. Percentage of southern pine seed infested with *Fusarium*, 10 seed lots, 100 seeds per lot 3/

	Slash	Shortleaf	Loblolly	Longleaf
	Percentage			
Range	31-100	23-100	18-100	7-99
Average	90.6	82.6	78.8	53.9

Fungicides applied as seed coatings provide a chemical barrier between germinating seeds and soil fungi. Furthermore, they prevent infection by fungi already present on the seeds. While fungicides may reduce seedling loss (Hamilton and Jackson 1951, Carlson and Belcher 1969), heavy doses often reduce germination (Carlson and Belcher 1969, Peterson 1970).

Because of container production's high costs, fungicides must control diseases without sacrificing quick vigorous germination. Several fungicides were tested for their effect on the germination of slash pine, loblolly pine, shortleaf pine, and longleaf pine seeds (Pawuk 1979). Fungicides were tested at 1, 2, 4, 8, and 16 oz ai per 100 lb. seed applied as a water slurry and the seed dried overnight. Results are shown in Table 2.

Table 2. Maximum fungicide dosages that did not inhibit seed germination of four southern pines

Fungicide	Slash	Lob-lolly	Short-leaf	Long-leaf
	Oz. ai/100 lb. of seed			
Captan 50 WP	16	16	16	16
Arasan 42-S	16	16	16	16
Terraclor 75 WP	4	16	16	8
Demosan 65 WP	4	16	16	8
Truban 30 WP	2	8	16	16
Banrot 40 WP	2	4	2	4
Dexon 35 WP	2	4	2	8
Terra-Coat SD-205 25 WP	2	8	4	16
Mertect 42 F	1	8	4	4
Benlate 50 WP	1	4	2	2
Busan^{R} 72 60 EC	0	4	2	4
Terra-Coat L-205, 30 L	0	4	2	4
	Percent			
Control germination	90	86	78	58

Slash pine seed was the most sensitive to fungicides. Longleaf and loblolly were most tolerant and shortleaf was intermediate. Captan and Arasan had the least effect on germination. All other fungicides reduced germination of one more species. This does not suggest that all ot fungicides should be discarded from consideratio Some may be quite effective against disease organisms at levels nontoxic to seed. Furthermo these tests were conducted in closed germination trays. Germination in the greenhouse may not be adversely affected as fungicides are washed from the seed with each watering.

For special seed lots, such as those used i breeding programs, disinfecting the seed with hydrogen peroxide may be desirable.

Even good fungicides may not eliminate *Fusa* entirely. Miller and Bramlett (1978) found that *Fusarium* and *Diplodia* may be present in the mega gametophytes and embryos of loblolly and slash p seed. Slash pine cones and seeds are susceptibl to infection before cone maturation.

SOILBORNE DISEASES

This discussion includes diseases commonly referred to as damping-off or root rot that are caused by fungi present in the growing media. I includes those that may in a strict sense be wat borne, that is they are introduced into the soil by contaminated irrigation water.

Species of *Fusarium*, especially *F. monilifo* are the fungi most commonly cultured from diseas seedlings and growing media. Attempts to cultur *Fusarium* from potting mixes prior to sowing have been unsuccessful. This indicates that it gets established and develops after containers are placed in the greenhouse.

I have cultured *Fusarium* from air and water samples in and around greenhouses, but always at low levels. While these sources cannot be ruled out, spread from infected seedlings during water ing is probably the most important source. *Fusarium* can often be seen producing abundant spores on infected seedlings. It spreads to the soil where there is a buildup of *Fusarium* with time. Fortunately, seedlings become more resist to infection as they mature.

Rhizoctonia has been observed on container-grown longleaf pine seedlings. In all cases it developed during periods when seedling foliage wa wet for extended periods. Spread is from seedli to seedling with the mycelium easily seen. The source of *Rhizoctonia* is not known. It is a com soil fungus that spreads in nature by movement o infected soil or plant debris from one area to another. It could easily be brought into greenhouses, as could other soil fungi, by workers or on tools and equipment. *Rhizoctonia* has been observed attacking seedlings in germination tray in the lab.

3/ W. H. Pawuk, unpublished data.

Water molds such as *Pythium* and *Phytophthora* my enter container nurseries through contaminated irigation water or by methods previously mtioned. They are favored by wet, poorly drained sils and cause root rot and damping-off of young sedlings. As seedlings mature, they become more rsistant, but root development and seedling growth cn be reduced.

Sound cultural practices can go a long way in pventing disease loss. Media should be pathogen fee from the start. It should be well drained ad seedlings should not be over watered. Equal rts of peat and vermiculite can be mixed to make agrowing medium that combines high cation excange capability, good moisture retention, and lw pH (Phipps 1974). Commercial media are aailable but most of these were developed for oher crops and have a high pH. Growth may be aceptable but disease development is favored.

Inoculation studies on longleaf seedlings by wuk (1981) using *Pythium* and *Fusarium* compared dsease development using several media. Best gowth was with equal parts peat and vermiculite (able 3). Less growth, but even better disease ctrol was achieved using pine bark, pine bark-vrmiculite, or pine bark-soil. Commercial peat vrmiculite, or pine bark-vermiculite mixes, with ahigher pH, had the greater disease incidence.

ble 3. Growth and disease development of longleaf seedlings grown on peat and bark media

dium [4/]	Final pH	Dry weight	*Fusarium*	*Pythium*
		mg	-----% loss	------
at				
V-50	5.1	798a[5/]	0a	40b
iffy Mix	6.2	755a	8bc	94e
rk				
V-50	5.2	510bc	0a	24ab
V-70	4.9	452cd	0a	16a
V-100	4.6	460cd	2ab	6a
S-70	5.1	530b	0a	16a
iffy 50-50	6.4	420d	16d	68d
iffy 70-30	6.4	410d	12c	88e

FUNGICIDES

Several fungicides are available that will ntrol damping-off and root rot if applied rrectly. There is no one fungicide cure-all at gives protection against all pathogens.

I have tested several fungicides for control of *Fusarium* and *Pythium*. Best results were with Benlate for *Fusarium* and Truban for *Pythium* at rates recommended on the label. When applied correctly, they give good disease control without phytotoxicity.

During studies with Benlate, applications were made immediately following sowing with no loss in germination. Truban was not tested this way, however.

Fungicides affect mycorrhizal development. Responses vary with fungicides and mycorrhizal symbionts. Not a great deal of work has been done in the area with southern pines, but some data are available. Pawuk and others (1980) tested the effect of several fungicides on the development of ectomycorrhizae on longleaf seedlings grown in pine bark media.

Pisolithus tinctorius ([Pers.] Coker and Couch) was completely inhibited by Terraclor, reduced by Captan and Dexon, not affected by Mertect and Truban, and stimulated by Benlate and Banrot. *Thelephora terrestris* (Ehr.) was greater on seedlings drenched with Benlate, Mertect, and Dexon than on the control. Terraclor and Truban reduce *T. terrestris*. Seedlings drenched with Terraclor had poor lateral root development suggesting that repeated use of this fungicide should be avoided in container nurseries.

Additional tests found that shortleaf pine seedlings grown in peat-vermiculite and drenched with Benlate, formed more mycorrhizal roots than undrenched seedlings (Pawuk and Barnett 1981). *Pisolithus* formed best at the highest level tested, 10 mg per seedling every 2 weeks. Highest Benlate levels also produced the largest seedlings.

Recently Marx and Rowan (1981) reported that drenches of Benlate and Captan increased mycorrhizal development by *P. tinctorius* and *T. terrestris* on loblolly pine in a bare-root nursery. Terraclor had no effect on either symbiont but Benodanil decreased infection by *P. tinctorius*. In this study, two drenches were made in early spring so the effect of repetitive dosages was not tested.

FOLIAGE DISEASES AND RUSTS

To my knowledge, foliage diseases have not been a problem on container-grown southern pine seedlings. This is probably due to the short period necessary to grow plantable seedlings and to the absence of prolonged periods when foliage is wet. The same can be said for the rusts, although seedlings could be infected with *Cronartium* rusts and symptoms would probably not be observed before they were shipped.

The possibility of rust infection should not be overlooked. Spraying with fungicides to prevent rust infection is not necessary. However, during the spring, seedlings should be

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[4/] The number following the medium signation indicates the percentage of peat bark present.

[5/] Means followed by the same letter are t significantly different, Duncan's Multiple nge Test at the 0.05 level.

watered early in the day so foliage is dry by night. This is especially true during wet weather when rust spores are released. I have seen rust infection on slash pine seedlings in an experimental greenhouse in Louisiana. Seedlings were purposely watered in the evening so foliage would be wet during the night to favor rust infection. Infection was only 3 percent compared to 65 percent for seedlings similarly treated and grown in an adjacent open shade house. The low rate of greenhouse infection was probably due to the absence of sufficient inoculum since air movement into the greenhouse was minimal. As long as the foliage remains dry, and greenhouses are closed at night, rust should not be a problem. When container seedlings are grown or held outside, seedlings should be sprayed to avoid rust infection.

LITERATURE CITED

Belcher, E. W., Jr., and B. T. Waldrip, Jr.
1972. Effect of Thiram on seed mold and germination of slash pine seed. Proc. Assoc. Off. Seed. Anal. 62:91-93.

Carlson, L. W., and J. Belcher.
1969. Seed treatment fungicides for control of conifer damping-off: laboratory and greenhouse tests, 1967-68. Can. Plant Dis. Survey 49: 38-42.

Hamilton, J. R., and L. W. R. Jackson.
1951. Treatment of shortleaf pine and loblolly pine seed with fungicidal dusts. Plant Dis. Rep. 35:274-276.

Marx, D. H., and S. J. Rowan.
1981. Fungicides influence growth and development of specific ectomycorrhizae on loblolly pine seedlings. For. Sci. 27:167-176.

Mason, G. N., and E. P. Van Arsdel.
1978. Fungi associated with *Pinus taeda* seed development. Plant Dis. Rep. 62:864-867.

Miller, T., and D. L. Bramlett.
1978. Fungi associated with damage to strobili, cones, and seed of slash and loblolly pines. Phytopathology News 12(9):27. Abstr.

Pawuk, W. H.
1978. Damping-off of container-grown longleaf pine seedlings by seedborne *Fusaria*. Plant Dis. Rep. 62:82-84.

Pawuk, W. H.
1979. Fungicide coverings affect the germination of southern pine seeds. U.S. Dep. Agric. For. Serv. Tree Planters' Notes 30(1):3-4.

Pawuk, W. H.
1981. Potting media affect growth and disease development of container-grown southern pines. U.S. Dep. Agric. For. Serv. Res. Note SO-268, 4 p.

Pawuk, W. H., and J. P. Barnett.
1974. Root rot and damping-off of containe- grown southern pine seedlings. Proc. Nort Am. Containerized For. Tree Seedling Sympo Great Plains Agric. Counc. Publ. 68:170-1

Pawuk, W. H., and J. P. Barnett.
1981. Benomyl stimulates ectomycorrhizal development by *Pisolithus tinctorius* on shortleaf pine grown in containers. U.S. Agric. For. Serv. Res. Note SO-267, 3 p.

Pawuk, W. H., J. L. Ruehle, and D. H. Marx.
1980. Fungicide drenches affect ectomycorrh development of container-grown *Pinus palus* seedlings. Can. J. For. Res. 10:61-64.

Peterson, G. W.
1970. Seed-protectant chemicals affect germination of ponderosa pine seeds. U.S. Agric. For. Serv. Tree Planters' Notes 21(25-29.

Phipps, H. M.
1974. Growing media affect size of containe grown red pine. U.S. Dep. Agric. For. Ser Res. Note NC-165, 4 p.

CONTAINERIZED WHITE PINE CULTURAL METHODS AND OUTPLANTING SUCCESS ON THE CUMBERLAND PLATEAU, TENNESSEE[1]

Ronald L. Hay and Joy K. Keegan[2]

Abstract.--White pine seedlings were grown in greenhouse culture for 7 and 12 months using combinations of supplemental light, carbon dioxide, and fertilizer treatments. Seedlings with the greatest biomass had received the 24-hour photoperiod and supplemental carbon dioxide. Secondary leaf development was also prolific. The mist foliar applications did not favor root growth.

Outplanting survival after the first field season was least for the 2-0 bareroot seedlings and the 24-hour photoperiod containerized seedlings. Although the natural photoperiod, natural carbon dioxide seedlings were the smallest at outplanting, they survived the best of all treatments.

INTRODUCTION

Why White Pine

East Tennessee is within the commercial range eastern white pine (Pinus strobus L.), and it is region in which sporatic logging of white pine uring this century has been strongly influenced by he intensity of market demands at the time. The outhern Appalachians were never the loci of extensive white pine logging activity, at least not imilar to that which swept the Northeast and Lake tates from 1850 to 1910. Still white pine has een here and it forms sizable stems in several orest types.

In the Southern Appalachians white pine occurs enerally between 1200 and 3500 feet elevation on ove sites, northern aspects, and along stream ottoms (Fowells 1965, p. 330). On the Cumberland lateau these truths are even more obvious! Scattered individuals and pockets of white pine grow long the creeks plus on the cool, moist sites of orthern slopes. Extensive coverage of large acreges that so enticed the early loggers into the orthwoods is lacking. Rather, white pines are istinctly evident in and above the mixed pine:hardood canopy as tall, scattered trees or small groups.

Forests on the Cumberland Plateau have long been logged, grazed, farmed or otherwise disturbed and todays stands reflect these abuses, superimposed upon succession and vegetation types. Most stands contain several age classes and several species representing various stages of successional development. White pine is occasionally one of these, but it is not a frequent component of any stand except where CCC plantations have survived the changing plans of man. Mostly the stands are mixtures of oaks, hickories, gum, yellow pines, and an occasional yellow-poplar, all of which are periodically tempered with a surface wildfire.

There are relatively few alternatives available to landowners who initiate forest management on their lands. Some stands have enough structure to justify and permit intensive management without starting afresh, but most stands lack structure. Species conversion is a realistic silvicultural possibility on these sites. White pine has sufficient biological economic and marketing attributes to warrant its use in species stand conversions.

White pine has demonstrated good growth in the Southern Appalachians on a variety of sites (Doolittle 1958). Only yellow-poplar on the very best sites had greater height growth than white pine in a comparison of site indices for 10 species common to the southern mountains. White pine volumes were superior for all site comparisons. Beck (1978) reported that white pine height and basal area growth on good sites were particularly impressive through 25 years, with 4.6 feet of height and 12 square feet of basal area produced per acre per year during the peak years. Volume yields were also good; such growth certainly warrants intensive management.

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With such excellent growth rates possible with white pine, high prices and ready markets complete the future for white pine. While the lower grades of oak lumber were selling for \$150 to \$170 per thousand board feet f.o.b. millyards on the northern Plateau in Tennessee, white pine lumber, mill-run grade, was selling for \$300 to \$350 per thousand. The market was so good that buyers parked their trucks at the greenchain to collect all the white pine lumber.

Containerized Culture

It can be a problem to grow white pine seedlings that have acceptable size and quality for outplanting. Some nurseries have grown them for four years as 2-2 transplants, others compromise with 3-0 or 2-0 seedlings. These programs all require substantial investments that raise the cost of seedlings. White pine seedlings at one year do not have sufficient size and they lack secondary needles that are necessary for good outplanting success. Therefore a second year in the seedbed is required, even though problems and costs mount.

Containerized seedling culture has many advantages over nursery culture, at least for some species. It's possible to start seedlings growing in containers and continue those growth processes through outplanting rather than wait for a dormant period to minimize the outplanting shock. Seedlings can be outplanted at a young age, thereby minimizing costs and some problems. The mycorrhizal inoculation possibilities are tremendous and almost unlimited. But white pine seedlings do not grow much different in containers than they do in the nursery bed during the first growing season.

White pine in containers growing under natural photoperiod and temperature regimes do not readily develop secondary leaves (Hay 1981) and they do not attain sufficient size for outplanting (Goodwin 1978). Outplanting failures are common, as influenced by time of planting and environmental conditions (Goodwin 1978). Seedlings that germinate in the spring or early summer will become dormant in autumn requiring an exposure to chilling temperatures before height growth will resume. If white pine seedlings that are suitable for outplanting are to be obtained using greenhouse containerized culture, growth amelioration treatments must produce seedlings with good-sized tops (12-20cm), secondary leaves, good root/shoot ratio, and easily plantable root plugs. Mycorrhizal infection may also be required, depending on the planting site characteristics.

The objectives of these studies were to produce white pine seedlings of acceptable size in less than eight months for outplanting on prepared forest sites using the following techniques:

a. 24-hour photoperiod,
b. carbon dioxide enriched atmosphere,
c. foliar mist spray with 25-10-10 fertilizer.

PROCEDURES

Greenhouse Culture

Treatment combinations of 24-hour photoperio or natural photoperiod, carbon dioxide (CO_2) enriched or natural atmosphere, maintenance fertilizer (20-20-20) and topdressing (25-10-10) with foliar mist spray were arranged in a randomized block design. Two sizes of rootrainers, Hillson (175 cubic centimeters) and super-45 (740 cubic centimeters), were used but they were not part of the design. All experiments were conducted in ventilated and cooled, glass greenhouses on the UT-Knoxville campus.

The 24-hour photoperiod was provided by a bank of 40-watt Gro-Lux fluorescent lamps spaced across each bench. The lamps were maintained wit 30 to 40 centimeters of the foliage. A black, plastic screen separated the 24-hour and natural photoperiod treatments during the dark period. I was intended that seedlings in the 24-hour photoperiod be given every opportunity to grow at maximum rates, at least in relation to photoperiod.

The dark portion of the natural photoperiod treatment was interrupted by 60 minutes of incandescent light to prevent dormancy. There was no intention nor enough light intensity to aid growt during the dark period for those seedlings.

Carbon Dioxide

Carbon dioxide was supplied to one greenhous by a propane burner from early November through late March. This period approximated the heat-requiring period; at other times ventilation was required at night. Depending on the intensity of the sun, ventilation was frequently required durin daylight hours in the winter. CO_2 enrichment was only effective at night and during the heating season.

The CO_2 generator was initially active from 8:00 p.m. until 10:00 a.m. until a more efficient schedule was developed. To give the seedlings every opportunity to use the enriched CO_2 before ventilation was required, the generator was soon shut off at 5:30 a.m. Later, in an attempt to maximize CO_2 enrichment advantages and still maintain some semblance of a budget, the CO_2 generator was put on a 6:00 p.m. to 10:00 p.m. schedule. This provided a boost in CO_2 concentration for all seedlings in that house as they entered the dark-phase of photosynthesis, i.e., the assimilation of CO_2 into carbohydrates using energy transformed during the light phase. Those seedlings growing under the 24-hour photoperiod treatment clearly had an advantage because they could still transfor light energy into chemical energy.

It was not possible to monitor CO_2 concentrations in the greenhouses because equipment sensitive to 300 ppm CO_2 was not available. Being fully cognizant of CO_2 toxicity at high concentrations (900 ppm on cucumbers - Aoki and Yabuki 1977) and unable to monitor our greenhouse, the CO_2 generator controls were set according to manufacturers guidelines for the air volume in the CO_2 greenhouse. It's possible that greater growth could have been attained with higher CO_2 concentrations. CO_2 toxicity symptoms were not evident on these white pine seedlings.

Fertilizers

Nutrients were added to the growth medium as 20-20-20 liquid fertilizers applied at watering on approximate 10-day intervals. All seedlings received this maintenance fertilizer treatment. Each sampling unit was split and one-half received a foliar mist topdressing of 25-10-10 on 20 day intervals. Every precaution was made to keep the 25-10-10 on the foliage due to the adverse effects that high nitrogen levels in the growth medium have upon ectomycorrhizal development (Dixon et al. 1979).

In all subsequent work, slow-release fertilizers (18-6-12) have been thoroughly mixed with the growth medium prior to filling the rootrainers. Without regard to the potential beneficial growth effects, the ease of operational logistics completely warranted the expense of slow-release fertilizers. Topdressings of water-soluble fertilizers can still be accomplished.

Rootrainers

As greenhouse containers, rootrainers were chosen for many of the reasons that Spencer-LeMaire, Ltd. say they are so good for growing tree seedlings. But which size to use? Much of the greenhouse culture of tree seedlings has been designed to have the seedlings ready for the field within two or three months after germination. White pine growth rates will not permit such a schedule (Goodwin 1978), so some of these seedlings were grown in the greenhouse for 12 months and some for 7 months.

How much root development volume was necessary? The super-45 was the largest rootrainer available and the Hillson was medium-sized. The other component to the question was the growth medium; clearly it's a joint contribution to solving root development problems. A commercially available medium of peat, sand, pea gravel, and shredded pine bark commonly used in ornamental nursery operations for container-grown plants was chosen. It was screened through 1 cm mesh hardware cloth.

At seven months of age, a sample of the seedlings in the Hillson rootrainers was harvested. Those remaining were outplanted on the Cumberland Plateau. The seedlings in the super-45 rootrainers were all harvested at 12 months of age; none of these were outplanted.

Outplanting

Outplanting Sites

The Cumberland Plateau is an extension of the Appalachian Plateau from Kentucky into Tennessee. The western boundary is the escarpment leading to the Highland Rim and the eastern boundary is the Cumberland Mountains, at least in the northern portion of Tennessee where white pine is native. Much of the northern Plateau remains as it was historically, i.e., it's forested, it's relatively isolated in that roads aren't much more abundant than when Boone came that way, and some remnant stands similar to those of E. Lucy Braun's day still contain noteworthy trees with northern affinities such as Fagus grandifolia, Acer saccharum and Taxus canadensis.

The topography on the Plateau proper is gently rolling; soils are underlain by massive sandstone parentrock relatively near the surface. On the western edge, streams have greatly eroded the plateau where some steep, rather spectacular gorges dominate the topography. Upland soils are sand and more sand, shallow, and not highly productive for sustaining tree crops. Sites along the drainages are more productive and support excellent tree growth.

At age seven months, white pine seedlings grown in Hillson-sized rootrainers were outplanted on Pickett State Forest, Pickett County, TN. The outplanting sites, along the Tennessee-Kentucky border on the Cumberland Plateau, had supported mixed pine-hardwoods of medium density and value. These stands were typical for the area, having developed after a history of high-grading, frequent fires, and several years of extensive management under state ownership.

The study sites had been clearcut the previous year, and site-prepared during the autumn before spring outplanting. One site had been sheared and the slash on the second site was pushed into rows, but the stumps were not sheared. Although disking was planned, it was never accomplished due to operational scheduling difficulties. Site I, the sheared site, was a southeast aspect and Site II was a northern aspect. Both had relatively shallow soils with slight humus development, and neither had sufficient chemical or physical properties to be highly productive.

Soil analyses of composite samples selected from various slope positions were uniformly low to very low in phosphorus, potassium, magnesium, and calcium. Ph ranged from 4.6 to 4.8, lacking a pattern as to slope or aspect. These facts were expected considering the geology of the area. This site was typical for this section of the Cumberland Plateau.

Five outplanting treatments were used on each site, in 6 replications each with 25-tree plots, namely,

a) Control--2-0 bareroot seedlings
b) 24-hour light with supplemental CO_2--7-month old containerized seedlings
c) 24-hour light without supplemental CO_2--7-month old containerized seedlings
d) Natural light with supplemental CO_2--7-month old containerized seedlings
e) Natural light without supplemental CO_2--7-month old containerized seedlings.

The trees were spaced 5 x 5 feet (1.5 x 1.5m) in order to satisfy the management objectives concerning the stand after some individuals were harvested for biomass analyses by age 5. The controls were planted on 26 March and the containerized seedlings were planted on 15 May, 1980.

During July in the first growing season, survival of all trees was recorded and a subsample of competing vegetation was made using two randomly selected seedlings as plot centers for a 1 meter radius nested plot. Percent cover and frequency were recorded for grass, herbs, and woody vegetation. Height and root collar diameter were recorded for the subsample seedlings. After the first growing season (November) the same measurements were repeated plus the total height, first-year height increment, and root collar diameter were recorded for each seedling.

RESULTS

Greenhouse

Seedlings used to test the effectiveness of the greenhouse culture techniques were measured and analyzed for height, root collar diameter, biomass of the tops and roots and root/shoot ratio. Table 1 is a summary of the adjusted means. Comparisons between ages should be made with the knowledge that there were differences in rootrainer sizes. However, neither the 7 nor the 12 month seedlings developed root systems that utilized the full-capacity of the rootrainer cavity. Neither did the roots hold the medium together well enough to ease handling during outplanting. This was an early indication that the growth medium was not wholly acceptable for greenhouse containerized seedling culture.

Light

The effects of photoperiod are presented in Table 1. Continuous light caused seedlings to grow more slowly in height than natural photoperiod, yet all biomass variables were significantly greater for the 24-hour photoperiod treatment. Height differences at 7 months were not significant, but after 12 months the seedlings grown under natural photoperiod were significantly ($P < 0.01$) taller. The trend in height growth at 7 months was veri at 12 months.

The 24-hour photoperiod treatment generall produced more than twice as much top and root b mass as the natural photoperiod during both the 7 and 12 month periods ($P < 0.01$). The accrued growth during the additional 5 months of the 12 month treatment produced biomass increases of 3 to 400 percent. Further tests using the same s rootrainer for varying periods are now underway

Particularly noteworthy were the changes i dry weight root/shoot ratios. At 7 months the root/shoot ratios were 25.4 and 19.1 percent re tively for 24-hour and natural photoperiods, i. the root dry weights were 1/4 and 1/5 as large a the top dry weights.

That's not enough roots! At 12 months, th root/shoot ratio had doubled from 7 months, and the proportions between photoperiod treatments were maintained. The changes in root/shoot rat were due to proportionally greater increases in root biomass than in shoot biomass.

Carbon Dioxide

The effects of CO_2 enrichment were not as great as those attributed to light. At seven months, the root fresh weight was significantly greater for seedlings grown in the CO_2-enriched house, but there were no differences in root dr weight or in root/shoot ratio. After 12 months the only significant difference was the root co diameter of plants with supplemental CO_2. The generator did not operate during the last 5 mon of the 12 month treatment, due to greenhouse ve tilation requirements.

Although there were few significant differ between CO_2 treatments, the evident trends all showed greater growth to have occurred on seedl in the CO_2 house.

Fertilizer

At 7 months, the foliar topdressing treatm had slowed seedling height-growth, however, by months this difference was not apparent. The t dressing seemed to have negligible effects on seedling top biomass, but after seven months a trend was developing that showed high-nitrogen topdressing to not be conducive to root biomass After 12 months this trend was confirmed, for r biomass was significantly less ($P < 0.01$) on tho seedlings receiving foliar topdressings of 25-1 Root/shoot ratio was also significantly less.

Outplanting

Growth, survival, and competing vegetation importance were measured in July and November o the first growing season in the field.

Table 1.-- Growth of eastern white pine seedlings in greenhouse culture for 7 and 12 months using light, carbon dioxide, and fertilizer treatments.

Greenhouse Treatment	Growth Variable						
	Height	Root Collar Diameter	Top Biomass		Root Biomass		Root/Shoot
			fresh	dry	fresh	dry	dry wt
	cm	mm	g	g	g	g	%
Photoperiod							
24-hour							
7-mos	7.3	2.3a	2.85a	0.84a	0.77a	0.20a	25.4a
12-mos	9.3y[1]	3.4	5.77x	2.52x	2.90x	1.30x	53.9x
natural							
7-mos	7.4	1.7b	1.39b	0.38b	0.35b	0.07b	19.1b
12-mos	10.5x	2.8	4.96y	1.41y	1.40y	0.51y	38.3y
Carbon Dioxide							
enriched							
7-mos	7.1b	2.0	2.11	0.64	0.63a	0.15	25.3
12-mos	10.1	3.2x	5.63	2.06	2.08	0.97	46.7
natural							
7-mos	7.6a	1.9	2.14	0.59	0.48b	0.12	20.9
12-mos	9.8	3.0y	5.10	1.87	2.22	0.85	45.5
Fertilizer							
Maintenance (20-20-20)							
7-mos	7.5a	2.0	2.10	0.60	0.62	0.15	24.1
12-mos	9.9	3.1	5.37	1.92	2.35x	1.01x	52.1x
Maintenance +topdressing (25-10-10)							
7-mos	7.2b	2.0	2.15	0.63	0.50	0.13	20.3
12-mos	10.0	3.1	5.36	2.01	1.95y	0.80y	40.0y

[1] The lower case letters indicate statistical significance groupings at the 99 percent level according to analysis of variance. The a-b group was used for seedlings at 7 months and x-y was used for 12-month seedlings.

Survival of the 2-0 bareroot seedlings was least of all treatments. These seedlings were sorted to some uniformity before carefully planting them in March, well within the planting season on the Cumberland Plateau. Current data are not available for comparison with survival of operational plantings in this same area.

Survival of all the containerized seedlings was significantly greater than the 2-0 bareroot stock. Table 2 showed that in July, those seedlings grown with natural photoperiod had greater than 90 percent survival. After the growing season, these treatments still had the highest survival percentages. In November both of the 24-hour photoperiod treatments were grouped with the control ($P < 0.05$) at lowest survival.

DISCUSSION

Somewhat contrasting evidence has been presented on how best to grow containerized seedlings in greenhouses for seven months and how best to maximize survival in the field after the first growing season. The largest, best-developed seedlings in the greenhouse were those growing in CO_2 enriched air using a 24-hour photoperiod, yet these seedlings showed the lowest field survival of all the containerized seedlings. Although all the containerized seedlings were similarly grouped ($P < 0.05$) by Duncan's Multiple Range Test, the 24-hour photoperiod seedlings were also grouped with the 2-0 bareroot seedling ($P < 0.05$). Their performance had not been much better than 2-0 seedlings, and neither one was highly acceptable. Greenhouse culture seedling growth attributes necessary for acceptable field performance in white pine have not been fully assessed nor appreciated.

Table 2.--Survival of white pine seedlings during the first growing season outplanted on prepared sites in Pickett State Forest.

Treatment	Survival	
	July	November
	%	%
2-0 bareroot seedlings	83.6b[1]	78.4b
Containerized seedlings		
24-hour light w/CO_2	89.2ab	82.8ab
24-hour light w/out CO_2	89.6a	86.0ab
natural light w/out CO_2	92.8a	90.0a
natural light w/CO_2	93.2a	89.2a

1/ Lower case letters refer to those means that were grouped as equal at the 0.05 probability level by Duncan's Multiple Range Test.

Seedling Relationships

The 24-hour photoperiod and CO_2 enriched treatment seedlings had more morphological characteristics similar to the 2-0 nursery seedlings than the remaining containerized treatments, e.g., the secondary leaves. They also survived in the field about as well, but the other greenhouse treatments were superior in first-year survival. It appeared that the extended photoperiod was the major influence upon these seedlings.

Biomass of both tops and roots was especially increased by the 24-hour photoperiod and to a lesser extent by the CO_2-enriched atmosphere. These seedlings appeared to have all the attributes necessary to grow well after outplanting. The tops had good quantities of secondary leaves, height and root collar diameter development were good and there was significantly more root biomass than on those seedlings grown without extra light and CO_2. The only apparent deficiency was the root/shoot ratio, which was low, yet the root/shoot ratios of these seedlings were the highest in the experiment.

By comparison, seedlings that had been grown with natural photoperiod and ambient CO_2 concentrations were less well-developed. They had few secondary leaves, they were significantly smaller at the root collar, had a poor root/shoot ratio, and they were the same height. Most tree planters would not have made them first choice for outplanting. Yet their survival in 1980 was best for all seedlings.

Extended Photoperiod Effects

The natural photoperiod during this study was first decreasing followed by a gradually increasing daylength from December through May 15. The dormancy-inducing effects of the decreasing daylength were broken by occasional interruptions of the dark period. Therefore the natural photoperiod trees continued to grow in height, but they did not accumulate large quantities of biomass.

It's important to note that all containerized trees were outplanted during an increasing daylength. Shortly before the anticipated outplanting, all seedlings were moved to lath shade for several days under natural photoperiod and temperatures. Seedlings that had been grown under the 24-hour photoperiod experienced a sharp decrease in daylength when they were moved to lath shade but the natural photoperiod seedlings only experienced changes in temperatures. About the time the 24-hour photoperiod seedlings had recovered from the shock, they were outplanted.

Although every care was taken to minimize outplanting shock, there was a definite change environment. There was little or no shade, water came infrequently at first and then not at all, and the temperatures were as high as they could be at that time of year. Even though care had been taken to minimize disturbance to the root plug during outplanting, there had to have been some shock and it would have been more severe on the 24-hour photoperiod seedlings.

Morphology of the 2-0 bareroot controls height growth was normal. The buds produced secondary leaves in the typical uni-nodal height growth pattern. At the termination of active height growth, buds were set for the next year. Height growth morphology of the containerized stock did not always follow this pattern.

When the containerized seedlings began active height growth after outplanting many of them grew rapidly producing primary leaves, even though secondary leaves from the greenhouse period may have already been present. It appeared that rapid growth was correlated with primary leaves production. Unfortunately, it was impossible to analyze the greenhouse growth treatments for this occurrence, but numerous seedlings were observed to have reverted from secondary to primary leaves. At outplanting, secondary leaves were frequent on the 24-hour photoperiod seedlings.

A Probable Scenario

Seedling root growth usually intensifies in early spring, prior to stem growth (Kramer and Kozlowski 1978, p. 102). Both temperature and photoperiod are stimuli influencing height growth timing and amount (Larsen 1965). Containerized seedlings grown with the natural photoperiod were able to respond to the increasing daylength before and after outplanting and they became well established through good root and shoot growth. Survival for these seedlings through the first year (90 percent) was quite acceptable.

Seedlings that were grown in the greenhouse under 24-hour photoperiod did not survive well, perhaps because they did not experience the same sequence of adjustments. It's possible that changes in photoperiod which occurred when the seedlings were moved first from the greenhouse to lath shade and then to the field caused changes in the sequence of root and shoot growth timing and amounts. These seedlings did not become well established shortly fter outplanting, rather they experienced a period f adjustment to the new photoperiod and tempera-ure regimen. Before this outplanting shock period as completed, East Tennessee was firmly in the rasp of the hottest, driest June and July ever ecorded.

The outplanting sites had been fully prepared arly enough in the winter that soil moisture was ear maximum when spring arrived. Furthermore, ite preparation had been thorough enough that ompeting vegetation was scarce, thereby permit-ing maximum soil water availability to all the hite pine seedlings. Those seedlings that were eady to grow shortly after outplanting had every dvantage. The weather was cloudy, wet and some-hat cool for several days after outplanting. How-ver, in early June the record drought and heat egan and lasted all summer. Seedlings that had ot begun to grow soon after outplanting experienced urvival problems.

In Retrospect

Containerized culture of white pine seedlings ith abundant attributes normally associated with trong outplanting successes may not be the complete tory. Seedlings were produced in seven months of reenhouse culture that had good secondary leaf evelopment, good root collar diameter, and good iomass of tops and roots. They most closely esembled the 2-0 nursery stock in morphological haracteristics, even though they were smaller. owever, when these seedlings were outplanted, heir survival was the poorest of all the contain-rized seedling treatments.

In the face of the hottest and driest June nd July in recent history, the containerized eedlings that produced the least growth, biomass, nd secondary leaves in the greenhouse, yielded 0 percent survival through the first growing eason. Perhaps more importance should be given o the physiological growth conditions of seedlings hen they are outplanted rather than emphasizing eedling size.

Greenhouse culture techniques should provide quick boost to seedling growth after outplanting y providing enough biomass plus the right physio-ogical condition at the right time. To obtain hese desired results, we may need to reassess our ulture programs that emphasize seedling size.

LITERATURE CITED

Aoki, M. and K. Yabuki.
1977. Studies on the carbon dioxide enrichment for plant growth. VII. Changes in dry matter production and photosynthetic rate of cucumber during carbon dioxide enrichment. Agr. Meteorol. 18:475-485.

Beck, D. E.
1979. Growth and yield of white pine, p. 72-90. Symposium for the Management of Pines of the Interior South. U.S. Forest Service Technical Publication. SA-TP2.

Dixon. R.K., H. E. Garrett and G. S. Cox.
1979. Containerized shortleaf pine seedlings show superior growth and ectomycorrhizal development with mist foliar application. Southern J. Applied For. 3:154-157.

Doolittle, W. T.
1958. Site index comparisons for several forest species in the Southern Appalachians. Soil Sci. Am. Proc. 22:455-458.

Fowells, H. A.
1965. Silvics of forest trees of the United States. U.S. Forest Service Agriculture Handbook No. 271. p. 762.

Goodwin, O.C.
1979. Performance of white pine containerized seedlings in North Carolina, p. 162-169. Symposium for the Management of Pines of the Interior South. U.S. Forest Service Technical Publication SA-TP2.

Hay, R. L.
1981. Growth of eastern white pine seedlings using greenhouse culture techniques. p. 46-49. First Biennial Southern Silvicultural Research Conf., Proc. U.S. Forest Service Gen. Technical Report SO-34.

Kramer, P. J. and T. T. Kozlowski.
1979. Physiology of woody plants. Academic Press. N.Y. p. 811.

Larson, P. R.
1963. Stem form development in trees. For. Sci. Monogr. #5.

DORMANCY AND COLD-HARDINESS OF CONTAINERZIED LOBLOLLY PINE SEEDLINGS[1]

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Abstract.--Successful regeneration using containerized seedlings is dependent upon matching the physiological state of the seedling to the physical state of the environment. This paper discusses seedling dormancy and cold-hardiness as they impact regeneration success. Methods of inducing cold-hardiness and overcoming dormancy are discussed as well as the consequences of mismatching seedling and environment.

INTRODUCTION

In 1980, the Southeastern nurseries produced o r one billion seedlings. Most of these s dlings were produced in bare root nurseries, b an increasing number are being produced in c tainerized nurseries. Containerized seedlings o er certain advantages unavailable with bare r t seedlings. Included in these advantages are: (relatively short start-up time; (b) short c p rotation and (c) relatively long outplanting s son. The last two factors can allow for m tiple cropping in a conventional greenhouse. F southern pines, as many as three crops could b grown in a single year (Barnett, cited in Tinus a McDonald, 1979). Barnett proposes the f lowing outplanting periods for each crop: M -June, September-November, and February-March (g. 1). However, weather conditions can limit r eneration success during the prescribed o planting seasons. Regeneration success during t May-June planting seasons is limited by a quate soil moisture and preciptation, and s dlings can be outplanted during this period w hout special physiological conditioning.

Successful establishment during the other two s sons, however, may be limited by the physiologi l state of the seedling at time of outplanting. T physiological criteria which are major determ ants of regeneration success during these p iods are the levels of dormancy and cold-h diness attained by the seedlings. The focus of t s paper will be the manipulation of these param ers to ensure establishment success.

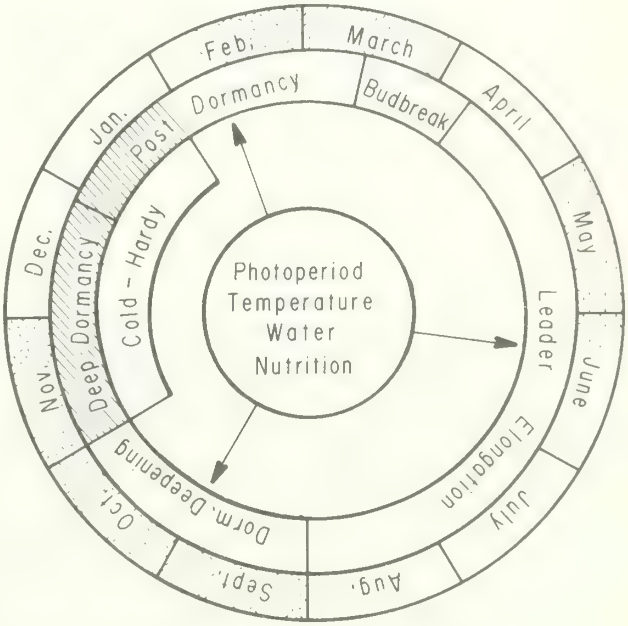

Figure 1. Growth cycle for loblolly pine. Stipled area represents outplanting seasons after Barnett (Tinus and McDonald, 1979).

DEFINITIONS

Cold-hardiness and dormancy are independent but frequently correlated biological processes. In a typical growth cycle, a seedling will become dormant prior to the development of cold-hardiness (fig. 1). Dormancy is the cessation of height growth, which will not resume without exposure to low temperature. In other words, the chilling requirement must be satisfied prior to the resumption of growth in the spring. Seedlings with a satisfied chilling requirement will grow normally and rapidly the next spring (fig. 2A).

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However, seedlings without a satisfied chilling requirement will not grow normally if at all the following spring (fig. 2B).

Cold-hardiness is the ability of a plant to survive subfreezing temperatures. The level of cold-hardiness varies seasonally from about -2°C in summer to about -40°C during mid-winter. Cold-hardiness in the fall is usually preceded by the cessation of height growth and loss of hardiness in the spring is succeeded by bud break. Unhardened or dehardened seedlings when subjected to subfreezing temperatures suffer membrane rupture, loss of intracellular water and solutes, rapid desiccation, and death (fig. 2C).

COLD-HARDINESS

Cold-hardiness can be induced by placing the seedlings outdoors in the fall, exposing them to progressively lower temperatures (Mexal, et al., 1979). Lengthening the exposure period from 0 to 6 weeks significantly increased the level of cold-hardiness as well as survival and growth (Table 1). Seedlings left in a heated greenhouse maintained their low level of hardiness (-4.3°C) throughout the exposure period. Failure to acclimate the seedlings has resulted in establishment failures following winter planting (Goodwin, 1974).

Cold-hardiness can also be accomplishec y the induction of dormancy through short phot er (Mexal, et al., 1979). The photoperiod test w 8 h and resulted in hardiness levels compara e to outdoor exposure to low temperatures. Gr in at low density and subjecting the trees to w er stress (-800 to -1700 kPa) has been proven t pr mote cold-hardiness of containerized Douglas ir seedlings (Tanaka and Timmis 1974). Fertili ti does not seem to impact the ability of a see in to become cold-hardy; except in the extreme se (Levitt, 1956, Timmis, 1975, Christersson, 1 5). Still, many growers reduce nitrogen levels a fertilize with KCL in the fall to promote "hardiness". However, Hinesley and Maki (19) failed to demonstrate any benefit to potassi fertilization in the fall. The effects of f l fertilization on cold-hardiness have not bee ad quately demonstrated.

It is important to understand the diffe nc between the cold-hardiness of shoots and tha of roots. Seedling root systems are usually we - insultated from very cold temperatures by th rooting medium, typically, soil. Because o hi insultation, root systems are neither requi n capable of attaining the same level of hardi ss as the shoots. However, containerized root systems, especially if they are outdoors, ca be subjected to lethal temperatures. Seedlings

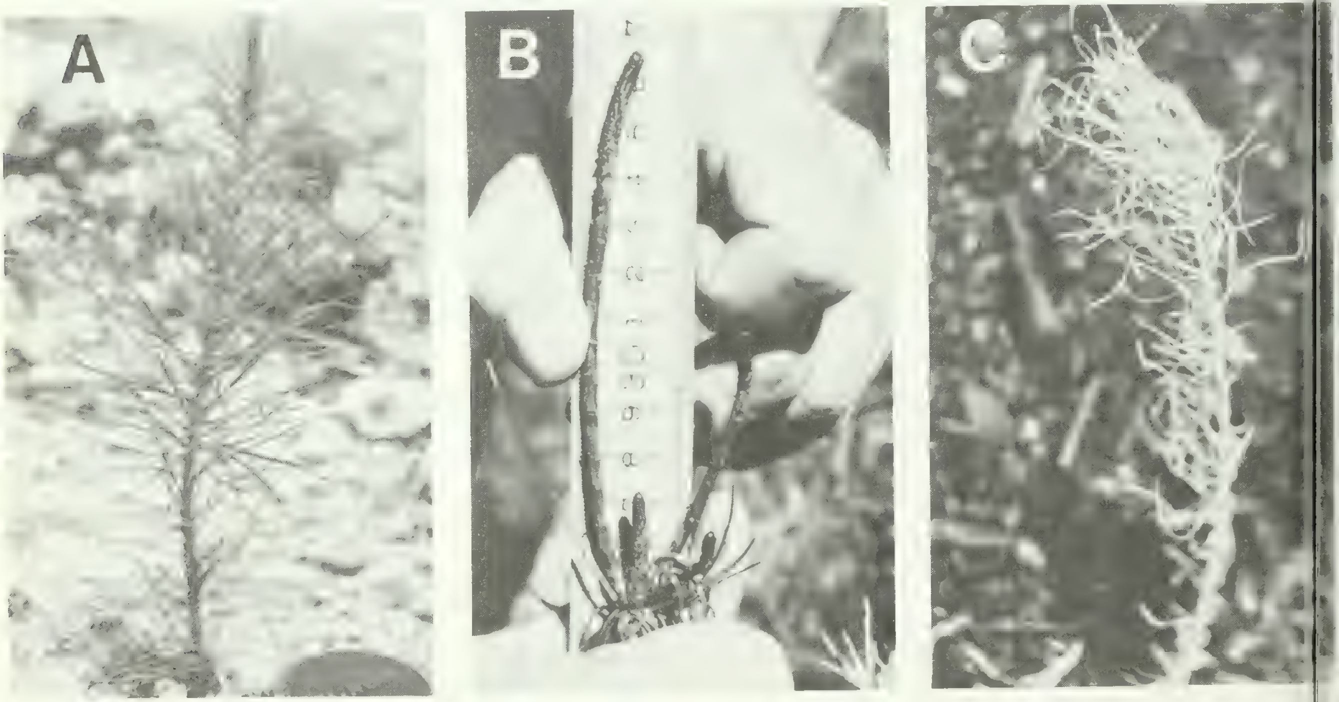

Figure 2. Containerized loblolly pine seedlings: (A) growing normally, (B) growing abnormal due to incomplete satisfaction of the chilling requirement and (C) dead from freezing temperatures.

Table 1. Cold-hardiness and field performance of containerized loblolly pine (Mexal, et al., 1979). All values are significantly different ($\alpha = .05$) according to Duncan's Multiple Range Test.

Exposure (wks)	Cold-hardiness (LT_{50})[1]	First year field survival (%)	Height Growth (cm)
0	-4.3°C	28	3.9
2	-6.4°C	52	10.1
6	-13.6°C	76	18.2

[1] Temperature at which 50% of the seedlings are killed.

often are placed on raised beds to promote root pruning. This allows for circulation of subfreezing air and increases the chance for root damage.

The damaging effects of lethal temperatures on root systems are not immediately obvious as they are in shoots. Seedling mortality, or even morbidity will not be obvious until the shoots are placed in a favorable environment. Significant damage to a container crop occurred in 1980 as a result of exposure to -10°C in early February. Survival for eleven provenances averaged less than 50% when brought into a greenhouse on 15 February; compared to over 90 percent on 24 January (Table 2). If seedlings are to be overwintered outdoors, precautions must be taken to prevent this damage. Precautions as simple as protecting with styrofoam sidewalls should provide adequate root protection for most regions.

DORMANCY

Dormancy is induced in the fall by short photoperiods and cool temperatures. Once a seedling has become dormant it will not resume growth until its chilling requirement has been satisified. The chilling requirement, or the amount of exposure to low temperature which will permit height growth when placed in a favorable environment varies with the species (Table 3) and can vary with the temperature regime. Generally, exposures of 4 to 12 weeks to temperatures less than 5°C completely satisfy the chilling requirement of most species. Loblolly pine requires about seven weeks exposure to natural conditions during November and December to completely satisfy the chilling requirement (Garber and Mexal, 1980). Following exposure for seven weeks, the terminal buds will expand rapidly and uniformly when placed in a growing environment. Partial satisfaction will result in slow budbreak or perhaps no bud break at all.

Table 2. Survival of loblolly pine seedlings grown outdoors and placed in a greenhouse on the dates listed below. Seedlings were exposed to -10°C on February 2, 1980. Survival was measured after 60 days. Number in parentheses represents the number of sources from a region.

Provenance	January 24	February 5	February 15
Alabama/Mississippi (2)	98%	70%	48%
Arkansas/Oklahoma (4)	97%	55%	46%
North Carolina (5)	94%	45%	58%

Table 3. Chilling requirement for dormancy release of conifers.

Species	Exposure		Source
	Length (wks)	Temperature (°C)	
Picea glauca	4 - 8	≤ 5°	Neinstaedt 1966
Pinus monticola	4 - 5	≤ 5°	Steinhoff & Hoff 1972
P. sylvestris	8 - 10	Natural (Nov.-Dec.)	Jensen & Getherum 1967
P. strobus	8	≤ 5°	Berry 1965
P. taeda	7	Natural (Nov.-Dec.)	Garber & Mexal 1980
Pseudotsuga menziesii	8 - 12	≤ 4.4°	Van den Driessche 1975
coastal			Wommack 1964
mountain		4°	Wells 1979
Tsuga heterophylla	8	≤ 5°	Nelson & Lavender 1979

Failure to break bud and grow the first summer following outplanting will negate much of the benefits of container planting. The effect is short term, however. The chilling requirement of the bud will be satisfied the following winter and subsequent growth will be normal. As an aside it is not known if small containerized seedlings which have not formed a terminal bud have a chilling requirement. However, this does not negate the requirement for cold-hardiness.

While there is information available regarding the natural chilling requirement for loblolly pine, there is no information on the artificial manipulation of the chilling requirement. Van den Driessche (1975) found cold-storage could partially satisfy the chilling requirement of Douglas-fir seedlings; and Tinus and McDonald (1979) stated that most species have the chilling requirement satisfied by four to five weeks of cold storage. Lavender and Hermann (1970) found exposure to low levels of light during storage of Douglas-fir was also important to subsequent growth. This information is not published for southern pines. Yet it is crucial to the development of management strategies for containerized seedlings.

MANAGEMENT PRESCRIPTIONS

Maximum survival and growth of containerized seedlings is the management goal of a container production facility. To attain these goals, careful attention must be given to the cold-hardiness and chilling requirements of the seedlings. Attaining the proper level of cold-hardiness is probably the more important of the two since cold damage can quickly result in death. However, failure to overcome bud dormancy can also negate many of the potential benefits ascribed to a containerized seedling. At the very least, one entire growing season will be lost. The loss may be much greater if competiting vegetation is not controlled, and the seedlings become shaded.

In addition to growth loss, seedling establishment may suffer if the chilling requirement is not satisfied. Ritchie and Dunlap (1980 indicated the root growth potential (RGP) of Douglas-fir seedlings reaches a maximum when the chilling requirement is completely satisfied. Therefore, not only is rapid shoot growth assure by satisfaction of the chilling requirement, but also rapid root growth to ensure survival from summer drought.

Much of the regeneration with containerized seedlings will occur during the fall and winter. To achieve high survival and growth potential, t seedlings should be placed outdoors during September or early October. Water stress and nutrient depletion can be initiated when the seedlings achieve target size, if desired. Outplanting of cold-hardy seedlings can occur throughout the winter. In certain regions, wher precipitation is adequate, containerized seedlin can be outplanted during September and early October. The seedlings will acclimate naturally in the field; thereby becoming cold-hardy and al satisfying their chilling requirement.

If the seedling crop does not achieve targe size until November or December, outplanting is best delayed until the spring. In that case, the chilling requirement of seedlings must be me prior to outplanting. This is best accomplished by reducing the greenhouse temperature and protecting the seedlings from freezing. Chilling f about seven weeks should satisfy the chilling requirement. Outplanting can occur in March in most regions.

Regeneration success depends on the physiological status of the seedling. Success with containerized seedlings is dependent upon ahing the physiological state of the seedling ohe physical state of the environment at time foutplanting. Careful attention to the hiological state of the seedling and managing h crop accordingly will ensure regeneration suce.

LITERATURE CITED

ey, C. R.
65. Breaking dormancy in eastern white pine by cold and light. U.S.F.S. Res. Note SE-43, 3 p.

hstersson, L.
75. Frost hardiness development in rapid- and slow-growing Norway spruce seedlings. Can. J. For. Res. 5:340-343.

aber, M. P. and J. G. Mexal.
80. Lift and storage practices: their impact on successful establishment of southern pine plantations. N.Z.J. For. Sci. 10:72-82.

Godwin, O. C.
74. Field performance of containerized seedlings in North Carolina, pp. 324-328. In Proc. N. Am. Containerized For. Tree Seedling Symp., R. W. Tinus, W. I. Stein and W. E. Balmer (eds.), Denver, CO. Great Plains Agr. Coun. Pub. No. 68.

Hesley, L. E. and T. E. Maki.
980. Fall fertilization helps longleaf pine nursery stock. S. J. Appl. For. 4:132-135.

Jesen, K. F. and G. E. Gatherum.
967. Height growth of Scotch pine seedlings in relation to pre-chilling, photoperiod and provenance. Iowa St. J. Sci. 31:425-432.

Laender. D. P. and R. K. Hermann.
970. Regulation of the growth potential of Douglas-fir seedlings during dormancy. New Phyto. 69:675-694.

eitt, J.
956. The hardiness of plants. Academic Press, N.Y. 278 p.

Meal, J. G., R. Timmis and W. G. Morris.
979. Cold-hardiness of containerized loblolly pine seedlings. S. J. Appl. For. 3:15-19.

Neson, E. A. and D. P. Lavender.
979. The chilling requirement of western hemlock seedlings. For. Sci. 25:485-490.

Nienstaedt, H.
1966. Dormancy and dormancy release on white spruce. For. Sci. 12:374-384.

Ritchie, G. A. and J. R. Dunlap.
1980. Root growth potential: its development and expression in forest tree seedlings. N.Z.J. For. Sci. 10:218-248

Steinhoff, R. J. and R. J. Hoff.
1972. Chilling requirement for breaking dormancy of western white pine seedlings. U.S.F.S. Res. Note INT-153, 6 p.

Tanaka, Y. and R. Timmis.
1974. Effects of container density on growth and cold-hardiness of Douglas-fir seedlings, pp. 181-186. In Proc. N. Am. Containerized For. Tree Seedling Symp., R. W. Tinus, W. I. Stein and W. E. Balmer (eds.), Denver, CO. Great Plains Agr. Coun. Pub. No. 68.

Timmis, R.
1974. Effect of nutrient stress on growth, budset, and hardiness of Douglas-fir seedlings, pp. 187-193. In Proc. N. Am. Containerized For. Tree Seedling Symp., R. W. Tinus, W. I. Stein and W. E. Balmer (eds.), Denver, CO. Great Plains Agr. Coun. Pub. No. 68.

Tinus, R. W. and S. E. McDonald.
1979. How to grow tree seedlings in containers in greenhouses. U.S.F.S. Gen. Tech. Rep. RM-60, 256 p.

Van den Driessche, R.
1975. Flushing response of Douglas-fir buds to chilling and to different air temperatures after chilling. B. C. For. Ser. Res. Note #71, 22p.

Wells, S. P.
1979. Chilling requirement for optimal growth of Rocky Mountain Douglas-fir seedlings. U.S.F.S. Res. Note Int.-254, 9 p.

Wommack, D. E.
1964. Temperature effects on the growth of Douglas-fir. Ph.D. Diss., Ore. St. Univ., Corvallis.

PRODUCTION PRACTICES FOR GROWING EUCALYPTUS SEEDLINGS IN CONTAINERS[1]

John F. O'Meara
and
Mark V. Crow[2]

Abstract.--Eucalyptus seeds are collected, cleaned and pelletized. The seeds are then sown in either of two container types. After germination they are rearranged, fertilized and grown to a shippable size in 12-14 weeks. The seedlings are packed in wax covered cardboard boxes and are ready to be picked up and outplanted.

SEED ORCHARDS, SEED COLLECTION AND SEED TREATMENT

There are 12 Eucalyptus seed orchards scattered throughout central Florida consisting of four species of Eucalyptus. Eucalyptus camaldulensis (spanish source) and Eucalyptus tereticornis are found in the more northerly orchards while Eucalyptus grandis and Eucalyptus robusta are further South. All the orchards were established in cooperation with the U. S. Forest Service at Lehigh Acres, Florida.

E. grandis and E. robusta seed capsules are collected in early spring and late summer, respectively, while E. camaldulensis and E. tereticornis are collected in late spring. All seed capsules are collected using a bucket truck.

Each seed tree in the orchard is numbered and the U. S. Forest Service, through genetic testing, determines which trees meet the standards for seed collection. After the seed capusles are collected, they are dried in a solar seed drying room in mattress covers or paper sacks, depending on the quantity of capsules.

In the drying room it takes two to three weeks for the capsules to open and release the seeds. The seed and chaff are then separated from the capsules using a cement mixer with a screened top. The smaller particles fall through while the larger ones are held back.

The seed and chaff are then sent to the U. S. Forest Service (Lehigh Acres) for further cleaning. The chaff is separated from the seed using a forced air seed blower. The cleaned seed is then sent back to Herren Nursery for pelletizing.

A small pelletizing machine, developed by Professor W. F. Miller of Cornell University,[3] is used to coat the seeds. This machine moves a non-stick surface frying pan back and forth as well as in a circular motion. The Eucalyptus seed are placed in the pan, sprayed with Gelvatol[4] and sprinkled with #140 and #200 sand mix.[5] The Gelvatol is sprayed on the seeds, then sand is sprinkled on them. This process is repeated until the pelletized seed is about the size of a BB. They are then placed in a force draft oven at 95°F for about one hour to dry. The seed are stored in plastic containers and kept in a refrigerator until sowing.

CONTAINER TYPES

Herren Nursery uses two types of seedling containers to grow Eucalyptus. These are the

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[1] Paper presented at Southern Containerized Forest Tree Seedling Conference, Savannah, Georgia, August 25-27, 1981.

[2] Reforestation Section, Florida Division of Forestry, Collins Building, Tallahassee, FL 32301.

[3] Paper by T. F. Geary & G. Meskimen, USDA Forest Service, Southeastern Forest Experiment Station, Lehigh Acres, Florida 33936.

[4] Gelvatol 40/10 (free sample), Monsanto Corporation, Bircham Bend Plant, Indian Orchard, Massachusetts 01151.

[5] Sand purchased from Standard Sand and Silica Company, Post Office Box 35, Davenport, Florida 33837.

Leach Tube[6], a small plastic test tube like container, and Styrofoam Tray[7] with containers molded into the block.

Leach Tube

This tube was developed by Ray Leach in Oregon. It is 4.75 inches long, 1 inch in diameter and tapered at the bottom. It has four small lines down the inside to help prevent root spiraling. The tubes are held upright by a plastic tray which holds 280 tubes. The seeds are sown directly into the tubes held by the tray. After germination they must be separated into wire racks to the proper growing spacing of 25 seedlings per square foot. At Herren Nursery we use 4' x 8' wooden racks covered top and bottom with 1" mesh chicken wire.

Disadvantages: 1. When watering and fertilizing, all of the material does not reach the plants. Only that which hits directly in the tube is usable, the rest is lost in the openings between tubes. 2. After germination plants must be separated from the plastic holder and placed in wire racks at the proper growing spacing.

Advantages: 1. Trees can be separated according to size and placed accordingly in wire racks. Small seedlings can be given more attention and will catch up to larger seedlings. 2. Seedlings pull a little easier from these containers.

Styrofoam Trays

These trays are made of styrofoam material with dimensions 26" x 16.5" x 5". There are 77 cavities per tray and the seeds are sown directly into the cavities. The plug is 5" deep and tapered at the bottom with a diameter of 1 3/8". It has three small lines inside the tube to help eliminate root spiraling. These containers were developed by Tommy Smith of LaBelle Plant World in LaBelle, Florida.

Disadvantages: 1. Large trees cannot be separated from smaller trees. 2. Large area needed to store empty containers.

Advantages: 1. Cavities are already in the proper growing spacing (25/square foot) in the tray. They do not have to be rearranged. 2. Almost all water and fertilizer run-off flows into one of the containers which means less water and fertilizer is needed. 3. Trees can be grown to a larger size.

Presently the Division of Forestry sells container grown Eucalyptus in Leach tubes for $70/M and styro grown Eucalyptus for $80/M.

SOIL MIX

Soil is purchased in compressed bales wrapped in plastic for easy handling and storage. The potting soil is composed of Canadian sphagnum peat moss, vermiculite and perlite. The soil comes premixed at a pH of 5.5. It is placed in a cement mixer. Water and Osmocote[8] 14-14-14 fertilizer are then added and mixed with the potting soil.

SOWING PROCESS

The soil is packed in containers after it has been through the cement mixer. Each plug is pressed down 1/8" to 1/4" from the top of the container with a special packing tool. A sowing machine using gravity feed drops a pelletized seed in each cavity. The seed is then covered with moist vermiculite and placed in the shade field.

GERMINATION, REARRANGING AND WEEDING SEEDLINGS

After the sown containers are placed in the shade fields, it takes 6-10 days for germination. The freshly sown containers are kept under shade for the first four weeks to keep heavy downpours from thunderstorms from washing the seed or young seedlings from the containers. Four weeks after sowing the young seedlings in Leach tubes have to be rearranged in wire racks at the desired growing spacing of 25/square foot. They are then placed in full sunlight. The styrofoam trays do not need rearranging because they are made at the proper spacing. They are also moved into the full sun four weeks after sowing. Any doubles and weeds are removed at this time.

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[6] Leach Tubes and Holders - Ray Leach Cone-Tainer, 1500 N. Maple Street, Canby, Oregon 97013.

[7] Styrofoam Trays - LaBelle Plant World, Post Office Box 398, LaBelle, Florida 33935.

[8] Osmocote - Time release fertilizer - 3 month.

FERTILIZATION

Fertilization with a tractor spray rig begins three weeks after the Eucalyptus are sown. They are fertilized an average of three times per week with a special 15-25-20 liquid mix[9] until they reach shippable size.

We mix a 25 pound bag of 20-20-20 and a 25 pound bag of 10-30-20 with hot water to make a 21 gallon slurry of 15-25-20. This mix can be applied through overhead irrigation and mixed with water in a boom type sprayer. The concentration should never exceed 500 PPM of nitrogen.

SEEDLING SHIPMENT

Leach tube Eucalyptus are ready to ship when they reach 20 centimeters in height, while stryo Eucalyptus are 30 centimeters when ready for shipment.

Farm tractors pulling flatbed trailers bring in the racks of Eucalyptus from the field to the shipping shed. The racks are unloaded on stands and workers remove the shippable seedlings. Any seedlings too small to ship are placed back in the field. The Eucalyptus seedlings are pulled from the containers by hand. The seedlings are placed on the shipping table in bundles of 25, with 350 packed per box. The lids are put on the boxes and the trees are ready for shipment.

9/ Peters Fertilizer (powder) - Mix 25 pound bag 20-20-20 and 25 pound bag 10-30-20 equals to 15-25-20.

PRODUCTION OF CONTAINERIZED SOUTHERN RED OAKS AND THEIR PERFORMANCE AFTER OUTPLANTING[1]

William W. Elam, John D. Hodges, and David J. Moorhead[2]

Abstract.--To test effects of container size and growth media on production and field performance, seedlings of four southern red oaks, Quercus falcata var. pagodifolia Ell., Q. nuttallii Palmer, Q. shumardii Buckl. and Q. nigra L. were produced in a greenhouse using three container sizes (0.5 liter, 0.9 liter, and 1.9 liter) and two growth media (Pro-mix BX and 1:1 Pro-mix BX and fine sandy loam soil).

Twelve-week-old container seedlings were outplanted and field performance was compared to 1-0 nursery stock produced from the same seed lots.

In the greenhouse, stem length and shoot/root ratio increased with container size and leaf surface area was affected by the media.

Third year field data show that both container size and growth media affected seedling performance after outplanting. Seedlings from the small container did not perform as well as those from the larger containers, however, there was no significant difference between the two larger containers. Survival and growth of seedlings produced using 1:1 Pro-mix and soil was better than only Pro-mix. This was probably due to effects on root development after outplanting.

Overall, container seedlings produced using the 0.9 liter container and Pro-mix plus soil media had equal or better survival and growth when compared to the 1-0 bareroot stock.

INTRODUCTION

Production of containerized hardwood seed- ngs is well behind conifers. Our work with con- inerized southern oaks closely parallels early rk with conifers, i.e. matching species to con- iners and determining best media and nutrition quirements. Tinus' (1974) work with oaks pointed t that individual species information is neces- ry for optimum production of quality containered oak seedlings.

The reasons for using containerized seedlings r regeneration have been enumerated for years; they are essentially the same for hardwoods as for conifers. Some of those most often stated are: poor performance of conventional nursery stock, lengthening the planting season, inadequate natural regeneration, being able to use genetically super ior stock, manipulation of species composition and the speeding up of early growth. The importance of rapid early growth to withstand competition has been emphasized and is very important in regeneration of oaks. Survival of planted oak seedlings is often very good but height growth for the first 2 or 3 years may be very poor, often averaging only a few inches per year (Russell, 1971). Some studies have indicated that more rapid early growth with hardwoods may be possible with containerized hardwoods (Johnson 1974; White et al, 1970). This study was done to evaluate the use of containerized southern oaks in the regeneration of hardwood stands with selected species.

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[1] Paper presented at Southern Containerized Frest Tree Seedling Conference, Savannah, Georgia, Agust 25-27, 1981.

[2] Associate Forester, Forester and Graduate Rsearch Assistant respectively, Department of Frestry, Mississippi Agricultural and Forestry Eperiment Station, Mississippi State, MS 39762.

MATERIALS AND METHODS

Seeds of cherrybark oak (Quercus falcata var. pagodifolia Ell.), water oak (Q. nigra L.) and shumard oak (Q. shumardii Buckl.) were collected from selected trees in Noxubee and Oktibbeha counties of Mississippi. Nuttall oak (Q. nuttallii Palmer) seeds were collected from counties in the Delta region of Mississippi.

Stratified seeds were planted in April in three different size containers made from milk cartons. Container sizes were 1.9 liter (23 X 9.8 X 9.8cm), 0.9 liter (23 X 7 X 7cm), and 0.5 liter (23 X 7cm triangular in cross section). Two growth media were used; Pro-mix BX, a commercial potting media, and a 1:1 mix of Pro-mix BX and fine sandy loam soil. All combinations of species, container sizes and media were tested. There were 25 seedlings per treatment and 3 replications. Uniform spacing between plants was maintained. A 50% shadecloth was used in the greenhouse to reduce light intensity, and evaporative pad cooling was used to reduce excessive heat. A Hoagland's solution was used to supply nutrients; watering was by hand and as necessary. Seedlings were kept in the greenhouse for 9 weeks.

Three weeks before outplanting the seedlings were placed outside the greenhouse to acclimate them to full sunlight. Immediately prior to outplanting, 5 seedlings from each treatment were randomly selected and root/shoot ratio, leaf surface area, root weight, and total dry weight were determined. All seedlings for outplanting were measured for height, rootcollar diameter and number of flushes.

The outplanting was a randomized complete block design with 3 replications and 28 plots in each replication. Each plot consisted of 16 seedlings at 8 X 8 ft. spacings with 8 foot border strips between plots. The reps included all species, container size, and media combinations plus plots containing 1-0 nursery produced bareroot stock of the four oak species. The planting area was a somewhat poorly drained, level upland site which was of moderate suitability for the oak species according to the site evaluation technique of Baker and Broadfoot (1977).

Container seedlings were planted in holes drilled with a two-man, powered auger. Containers were removed, the media and root system inserted, packed in and covered with augered soil. Prior to planting the site had been disked to control competition.

Bareroot stock was grown from the same seed lots used for the container stock. They were planted in March using a hardwood planting spade.

Plots were disked twice per growing season to help control competition. Survival, rootcollar diameter and height were measured on all seedlings at the end of each growing season.

RESULTS AND DISCUSSION

Initial Seedling Development

Germination

Germination was not significantly affected by any treatment although after 65 days percent germination was slightly higher in the Pro-mix media. The usual drawn out germination period of water oak was not affected by either media.

After six weeks most seedlings had begun a second flush of growth with the exception of water oak (due to the delayed germination). Averages of morphological data of 12 week-old seedlings are shown by species in Tables 1, 2, 3, and 4.

Height

In general, height increased as container size increased and the Pro-mix medium was slightly better than the combination medium. The media effect is especially evident in Shumard oak (Table 3). Considering all species, Nuttall oak seedlings were consistently the tallest followed in order by Shumard oak, water oak, and cherrybark oak.

Root weight

Overall, treatment differences were small an not highly significant. Measured differences varied by species, Nuttall, Shumard and water oak had greater root weight in Pro-mix while cherrybark oak produced greater root weight in the combination media.

Root-collar diameter

Again, differences between treatments were small with few significant differences. Generally root collar diameter decreased with decreasi container size with the exception of water oak.

Leaf Surface Area

Leaf surface area tended to increase with increasing container size, and the Pro-mix media usually produced seedlings with the most leaf surface. In Shumard oak this difference was great enough to be statistically significant in all container sizes.

Root/Shoot Ratio

Generally, seedlings from the smallest containers grown in the combination media had greate root/shoot ratios than those from other treatment This may have been due to lack of adequate growth of the shoot system and not better development of the roots.

Table 1. Morophological development of 12-week old cherrybark oak as related to container size and growth media.

Container and Media	Stem Length (cm)	Root Weight (g)	Root-collar Diameter (mm)	Leaf Surface Area (cm^2)	Total Dry Wt. (g)	Root/Shoot Ratio
1.9 liter Pro-Mix	22.80 ab	1.06 ab	4.90 ab	221.93 ab	3.53 a	0.57 bc
1.9 liter Combination	26.00 a	1.41 ab	5.60 a	315.00 a	4.61 a	0.46 c
0.9 liter Pro-Mix	21.60 ab	0.80 b	4.30 b	303.58 a	3.08 a	0.36 c
0.9 liter Combination	22.90 ab	1.52 a	5.50 a	276.50 ab	3.61 a	0.58 bc
0.5 liter Pro-Mix	21.20 ab	1.15 ab	4.70 ab	180.80 ab	2.69 a	0.70 ab
0.5 liter Combination	17.00 b	1.22 ab	4.10 b	143.90 b	2.75 a	0.82 a

Note: Means not sharing a letter in common differ significantly at the 0.05 level by the Duncan's New Multiple Range Test.

Table 2. Morphological development of 12-week old Nuttall oak as related to container size and growth media.

Container and Media	Stem Length (cm)	Root Weight (g)	Root-collar Diameter (mm)	Leaf Surface Area (cm^2)	Total Dry Wt. (g)	Root/Shoot Ratio
1.9 liter Pro-Mix	39.30 a	2.43 a	7.70 a	411.76 a	8.04 a	0.45 b
1.9 liter Combination	46.40 a	2.26 ab	7.20 a	365.64 a	8.18 a	0.42 b
0.9 liter Pro-Mix	44.20 a	2.81 a	7.20 a	418.50 a	8.36 a	0.51 b
0.9 liter Combination	44.90 a	2.04 ab	7.30 a	356.40 a	6.89 a	0.42 b
0.5 liter Pro-Mix	36.12 a	2.10 ab	6.60 ab	280.43 a	6.13 ab	0.52 b
0.5 liter Combination	24.70 b	1.57 b	5.70 b	116.13 b	3.46 b	0.85 a

Note: Means not sharing a letter in common differ significantly at the 0.05 level by Duncan's New Multiple Range Test.

Table 3. Morphological development of 12-week old Shumard oak as related to container size and growth media.

Container and Media	Stem Length (cm)	Root Weight (g)	Root-collar Diameter (mm)	Leaf Surface Area (cm^2)	Total Dry Wt. (g)	Root/Shoot Ratio
1.9 liter Pro-Mix	34.80 ab	2.72 a	6.00 a	470.17 a	7.33 a	0.59 b
1.9 liter Combination	27.90 bc	2.22 a	5.70 ab	290.03 b	5.06 bc	0.82 ab
0.9 liter Pro-Mix	36.10 a	2.61 a	5.60 ab	470.40 a	6.82 ab	0.61 ab
0.9 liter Combination	21.40 cd	2.57 a	5.50 ab	274.80 bc	5.26 bc	0.98 a
0.5 liter Pro-Mix	25.20 c	2.44 a	4.90 b	303.95 b	5.29 bc	0.92 ab
0.5 liter Combination	16.60 d	2.07 a	5.00 b	189.99 c	3.95 c	1.14 a

Note: Means not sharing a letter in common differ significantly at the 0.05 level by Duncan's New Multiple Range Test.

Table 4. Morphological development of 12-week old water oak as related to container size and growth media.

Container and Media	Stem Length (cm)	Root Weight (g)	Root-Collar Diameter (mm)	Leaf Surface Area (cm^2)	Total Dry Wt. (g)	Root/Shoot Ratio
1.9 liter Pro-Mix	23.90 a	1.15 a	4.30 a	203.63 a	3.50 a	0.58 ab
1.9 liter Combination	29.70 a	0.44 c	3.60 a	213.05 a	2.53 a	0.23 c
0.9 liter Pro-Mix	28.60 a	0.87 ab	4.10 a	219.86 a	3.27 a	0.35 bc
0.9 liter Combination	24.30 a	0.68 bc	3.90 a	138.56 a	2.33 a	0.45 abc
0.5 liter Pro-Mix	22.90 a	0.75 bc	4.00 a	189.21 a	2.69 a	0.35 bc
0.5 liter Combination	17.90 a	0.86 ab	4.50 a	114.33 a	2.26 a	0.66 a

Note: Means not sharing a letter in common differ significantly at the 0.05 level by Duncan's New Multiple Range Test.

Total dry weight

Total dry weights of the seedlings were not greatly affected by the treatments. In cherrybark oak and water oak there were no significant differences and only the small container seedlings had significantly lower weight in Nuttall oak. Shumard oak seedlings showed a significant media effect in which Pro-mix produced the heavier seedlings regardless of container size.

Evaluation of the measured morphological variables point out that generally: (1) seedling size increased with increasing container size, (2) seedlings grown in Pro-mix had better shoot growth regardless of container size, (3) seedlings produced in the 0.5 liter containers with the combination media were the poorest, and (4) for practical purposes seedlings produced in the 0.9 liter container appeared to be the most suitable for outplanting purposes since the ease of handling the smaller container overshadowed the advantage of the slightly larger size of seedlings produced in the largest (1.9 liter) container.

Field Performance

Survival and growth data by species are shown in tables 5, 6, 7, and 8 for containerized and bareroot seedlings. Final data were taken after 3 complete growing seasons in the field.

Survival

Although survival was acceptable in all treatment combinations, there was an apparent media/container size effect on survival in all species. In the largest container, seedlings in the combination media had the highest survival in all species. Media effect was not apparent in the .9 liter container with survival about equal across treatments, however in the smallest container the trend is toward higher survival in the Pro-Mix media.

We believe this may be due to the differences in movement of soil water within the media. The pore space of the combination media is smaller and would accomodate capillary movement of water more readily than the Pro-Mix. In the largest container this effect would be more pronounced than in the other size containers. All seedlings were carefully planted so that the media was well covered by soil so we do not think this is due to any type of wicking effect. Differences in root growth of seedlings as affected by media is now being investigated with respect to survival and growth.

rowth

Growth of seedlings in the combination media as superior in all container sizes with the excepion of water oak in the smallest container. Overll there is a significant difference in the height nd root collar diameter between the small container nd the two larger (Tables 5, 6, 7, 8). Between the two larger size containers, seedlings grown in the .9 liter container with the combination media are equal to or superior in growth to the 1.9 liter size (Tables 5, 6, 7, 8) with the exception of cherrybark oak where the large container is best.

Comparison with 1-0 nursery stock

In all species except cherrybark oak the 0.9 liter combination seedlings are larger and growing at a faster rate than the 1-0 bareroot stock after three years in the field. Survival is 98% or better compared to over 90% for the bareroot.

In cherrybark, even the best container seedlings are not as large as the bareroot seedlings after three years although they are growing at a faster rate. Part of this is due to our lack of expertise in producing adequate containerized cherrybark oak seedlings. In producing the seedlings used in this study, we found that cherrybark is much more sensitive to nutrients and media than the other three species. This points up the fact that more species specific work is necessary if we are to produce the optimum containerized oak seedling.

General Summary

Four species of containerized oak seedlings were produced to field test against comparable bareroot stock. Of the three container sizes and growth media tested, based on space, handling, planting ease and quality of seedlings, the best size of the three tested was 0.9 liter. Based on morphological data of 12-week-old seedlings, the best media was a Pro-Mix media; however third year field data shows that seedlings produced in a 1:1 soil and Pro-Mix combination media performed the best after outplanting in terms of both survival and growth. The effect of the media after outplanting could therefore be of more significance than in the greenhouse.

We found that cherrybark oak is more sensitive to containerization than Nuttall, Shumard or water oak. To produce the optimum containerized oak seedlings will require much more testing.

Field results are most encouraging. After three growing seasons the containerized seedlings have survived as well as or better than the bareroot stock. In terms of growth, the container plants are growing at a faster rate and (excluding cherrybark) are now taller and have larger root collars than the bareroot plants.

Cost of producing the container seedlings versus cost of producing bareroot seedlings was not analyzed.

Table 5. Average size and survival of containerized and nursery produced Shumard oak seedlings 3 growing seasons after outplanting.

Container Size & Media	Size at Outplanting Height (cm)	Size at Outplanting Root Collar (mm)	Size after 3 seasons Height (cm)	Size after 3 seasons Root Collar (mm)	Increase Height (cm)	Increase Root Collar (mm)	Survival %
1.9 L Pro-mix	35.6	5.4	56.9	12.7	21.3	7.3	85
1.9 L Comb.	32.6	4.9	95.0	20.6	62.4	15.7	92
.9 L Pro-mix	40.4	5.3	78.9	17.9	38.5	12.6	98
.9 L Comb.	25.7	5.1	99.3	19.5	73.6	14.4	100
.5 L Pro-mix	23.1	4.9	70.1	13.9	47.0	9.0	98
.5 L Comb.	13.5	4.5	68.6	14.3	55.1	9.8	83
Nursery[1/]	54.8	8.2	88.3	17.6	33.5	9.4	90

[1/] Planted as 1-0 bareroot stock.

Table 6. Average size and survival of containerized and nursery produced water oak seedlings 3 growing seasons after outplanting.

Container Size & Media	Size at Outplanting Height (cm)	Size at Outplanting Root Collar (mm)	Size after 3 seasons Height (cm)	Size after 3 seasons Root Collar (mm)	Increase Height (cm)	Increase Root Collar (mm)	Survival %
1.9 L Pro-mix	20.6	4.1	120.0	23.3	99.4	19.2	92
1.9 L Comb.	19.3	3.9	198.0	37.7	178.7	33.8	100
.9 L Pro-mix	23.1	4.6	154.8	30.6	131.7	26.0	98
.9 L Comb.	22.5	4.4	209.8	40.5	187.3	36.1	98
.5 L Pro-mix	20.7	3.8	175.8	31.2	155.1	27.4	94
.5 L Comb.	17.9	3.8	164.4	30.3	146.5	26.5	96
Nursery[1/]	45.4	7.2	160.4	31.2	115.0	24.0	98

[1/] Planted as 1-0 bareroot stock.

Table 7. Average size and survival of containerized and nursery produced cherrybark oak seedlings 3 growing seasons after outplanting.

Container Size & Media	Size at Outplanting Height (cm)	Size at Outplanting Root Collar (mm)	Size after 3 seasons Height (cm)	Size after 3 seasons Root Collar (mm)	Increase Height (cm)	Increase Root Collar (mm)	Survival %
1.9 L Pro-mix	21.0	4.2	59.4	13.9	38.4	9.7	77
1.9 L Comb.	26.6	4.7	89.2	19.9	62.6	15.2	98
.9 L Pro-mix	22.9	4.3	80.6	19.8	57.7	15.5	92
.9 L Comb.	22.8	4.4	81.7	15.6	58.9	11.2	98
.5 L Pro-mix	18.4	4.1	57.5	13.8	39.1	9.7	77
.5 L Comb.	15.5	4.1	61.2	14.6	45.7	10.5	79
Nursery[1/]	44.4	8.1	96.4	22.3	52.0	14.2	98

[1/] Planted as 1-0 bareroot stock.

Table 8. Average size and survival of containerized and nursery produced Nuttall oak seedlings 3 growing seasons after outplanting.

Container Size & Media	Size at Outplanting Height (cm)	Size at Outplanting Root Collar (mm)	Size after 3 seasons Height (cm)	Size after 3 seasons Root Collar (mm)	Increase Height (cm)	Increase Root Collar (mm)	Survival %
1.9 L Pro-mix	38.7	5.9	186.6	37.5	147.9	31.6	92
1.9 L Comb.	37.3	6.1	222.5	43.9	185.2	37.8	98
.9 L Pro-mix	43.2	6.6	207.8	42.6	164.6	36.0	98
.9 L Comb.	35.5	6.6	219.4	44.8	183.9	38.2	100
.5 L Pro-mix	35.0	6.2	201.2	39.2	166.2	33.0	100
.5 L Comb.	25.9	5.1	202.1	38.5	176.2	33.4	92
Nursery[1/]	87.9	11.5	192.9	41.0	105.0	29.5	98

[1/] Planted as 1-0 bareroot stock.

LITERATURE CITED

Baker, J. B. and W. M. Broadfoot.
1977. A practical field method of site evaluation for eight important southern hardwoods. USDA For. Serv. Gen. Tech. Rep. SO-14, 31 p.

Johnson, P. S.
1974. Containerization of oak seedlings for the oak-hickory region—a progress report, p 197-199, IN North Am. Containerized Tree Seedling Symp. Proc. Great Plains Agric. Publ. 68.

Moorhead, David J.
1978. Effects of container size and growth media on the early growth and field survival of four southern red oak species. M.S. Thesis. Miss. State Univ., Miss. State, MS 75 p.

Russell, T. E.
1971. Seeding and planting upland oaks, p. 49-54, IN Oak Symp. Proc. USDA For. Ser. NE For. Exp. Sta. Upper Darby, Pa.

Tinus, R. W.
1974. Large trees for the Rockies and Plains, p. 112-118, IN North Am. Containerized Forest Tree Seedling Symp. Proc. Great Plains Agric. Publ. 68.

White, D. P., G. Schneider, and W. Lemmien.
1970. Hardwood plantation establishment using container growth stock. USDA For. Ser. Tree Planter's Notes. 21:20-25.

BARE ROOT VERSUS CONTAINERIZED SEEDLINGS:
A COMPARISON OF PRODUCTION PROBLEMS AND METHODS[1/]

H. Grady Harris[2/]

Abstract.--Bare root and containerized seedling production methods are compared from a supervisor's standpoint. The accelerated growth rate of containerized seedlings provides the advantage of flexibility in scheduling multiple annual crops, but causes some management problems. Ability to anticipate and attention to detail are required of the greenhouse manager. Advantages of containerized production are extended planting season and flexibility of crop scheduling; disadvantages are high production and transportation costs and logistic problems in field planting.

After more than forty-five years of bare root xperience, the North Carolina Division of Forest esources began operational production of conainerized forest tree seedlings in 1976. Con - ainerized production was initiated in an effort o alleviate a recurring shortage of Fraser fir *Abies fraseri*(Pursh) Poir) seedlings produced for hristmas tree growers in the mountains of the tate. A second objective was to extend the lanting season for Southern yellow pine species xtensively planted in the eastern two-thirds of orth Carolina. Since that beginning, crops of ontainerized fir, eastern white pine (*Pinus strobus*), loblolly pine (*Pinus taeda* L.), longleaf pine *Pinus palustris* Mill.) and slash pine (*Pinus lliotii* Engelm. var. *elliotii*) have been more-or-ss successfully produced. Perhaps a comparison the two production methods will be useful to hose interested in containerized production of rest tree seedlings.

Essentially, both bare root and containerized oduction methods consist of placing viable seeds a suitable medium and providing water, nutrients, d the necessary cultural practices to favor rmination of the seeds and development of the sulting plants into usable seedlings. However, e major difference between these methods becomes adily apparent when considering the establishment either type of facility.

The individual planning a bare root nursery thinks primarily of land for the site, because soil quality, available water and location in relation to the field planting area are so important to the success of the nursery. On the other hand, site is not nearly as important when considering the establishment of a containerized facility. The person planning such an operation must choose between a fairly wide variety of greenhouses, environmental control systems, container filling and seeding machinery, containers, and soil mediums. To help insure choices that will allow all parts of the operation to fit together in an efficient system that meets specific organizational requirements, the designer should visit as many existing facilities as possible. Before the installation of the North Carolina Division of Forest Resources was designed, a senior staff forester of the Division visited established operations in seven states and at three Canadian locations.

The greatest difference between these two seedling production system is the accelerated growth rate attained by containerized seedlings. Of course, this increased growth rate results from the optimum conditions for growth that can be maintained in the greenhouse where the seedlings are grown. Some management options unavailable in bare root production results from this accelerated growth, but it may also cause some problems, as will be seen later.

The accelerated growth rate gives much greater flexibility to the containerized operation. More than one crop can be produced annually; if the proper environmental controls were incorporated in the greenhouse, production of a crop can be begun at any time of year. This flexibility affects

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1/ Paper presented at Southern Containerized rest Tree Seedling Conference, Savannah, Georgia, gust 25-27, 1981.

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planning; the greenhouse manager must order supplies for three to five crops if ordering on a yearly basis, whereas, the bare root nurseryman orders for one crop at a time. Thus, the containerized operator has to anticipate to a much greater degree than does the bare root producer.

After planning, construction, and acquisition of the necessary supplies, seedling production can begin. The most important operation in the production process, seeding, comes first. Regardless of the quality of the after care, a high quality crop of the desired quantity of seedlings cannot be produced without a well-planned, well executed seeding operation. Because of its importance, seeding is discussed in some detail.

The bare root nurseryman must place on the bed the proper amount of seeds per hundred feet of bed to give the desired density of seedlings. Because of the long history of bare root production, a wealth of information is available to help this nurseryman calculate the sowing rate and apply the seeds. The practice is fairly standardized, although each individual nurseryman has probably developed his own minor variations from standard practice.

In contrast, the containerized nurseryman is not concerned with the weight of seeds that must be sown; in seeding containers one or more seeds must be put into individual cells so that the number of filled cells is maximized and the number of cells with multiple seedlings is minimized. Procedures are available to assist with the necessary calculations. Balmer and Space (1976) have developed probability tables which are useful in making seeding rate calculations; the same authors have prepared a computer program from which the most economic seeding rates can be derived (Space and Balmer 1977). Tinus and McDonald (1979) recommend use of these methods but also list rules of thumb that have been developed. The North Carolina Division of Forest Resources determines the number of seeds required to result in a probability of 100 per cent that one viable seed will be placed in each cell. Seeding is then carried out using that number of seed per cell. The individual containerized nurseryman will probably decide on the method to use based on the species and the value and quality of seed lots which are required in his operation. Regardless of the method used to determine seeding rate, the best seedlots available must be used for containerized production in order to hold production costs at the lowest possible level.

The containerized nurseryman may use one or more practices not practical in bare root production to improve the results of seeding. If space is available in the greenhouse, extra flats may be seeded and the resulting seedlings transplanted into blank cells. Thinning and transplanting may be used to reduce the number of cells with more than one seedling and to increase the number of filled cells. This practice may not be practical in some operations because of cost. Thinning alone may be used to correct overseeding by eliminating multiple seedlings in single cells Use of these practices depends upon the value of the crop produced, the value of the seed used, an the cost and availability of temporary labor.

In containerized production, cultural practi necessary for growth and development of the crop are easily carried out. Nutrients are applied with water through fixed or traveling irrigation systems automatically or manually. Competition from weeds and grasses is a minor problem; those weeds that do come in through the ventilation system can be removed by hand during routine inspections; weeds and grasses are prevented from becoming established under the benches by use of a pre-emergence herbicide, or if they do become established, by treatment with contact or systemi herbicides. If pests become a problem, pesticide can be applied directly onto the plants through the watering system. If necessary, the house can be closed. Treatment may have to be applied quickly; natural enemies of the pest are probably not established in the greenhouse and cannot be counted upon to slow the outbreak. Pesticide application should be quite effective because of the closed environment; the risk of environmental pollution is certainly minimal.

However, the bare root nurseryman spends at least four months heavily involved with cultural practices. Irrigation, fertilization, hand weeding, and pest control require a permanent cre and close supervision. In addition, two other practices not commonly used in containerized production, top and/or root pruning, may be used to equalize seedling size and reduce cull percentage

The bare root nurseryman need not be concern with light. His seedling crop grows outside in natural light, and requires a full growing season to develop to plantable size. In contrast, supplemental lighting is used in containerized production to prevent shoot dormancy during the dark hours and thus maintain a maximum rate of growth. Although supplemental lighting may not be necessary for optimum growth during the summer in the South (Tinus and McDonald 1979) such lighting may be required for the production of crops begun in early spring or late summer. In the greenhouse of the North Carolina Division of Forest Resources, the supplementary lighting system is turned on as soon as seeding is completed, and remains on until the crop is moved outside, regardless of the season of the year.

Time must be allowed for hardening-off the containerized crop. About as much time is requir for hardening-off as is required for growth to usable size. Containerized seedlings may be hardened-off by moving them to the outside benche and reducing the watering-fertilization schedule. In bare root nurseries hardening off follows the natural cycle; in September irrigation and fertilization are stopped, and the seedlings harden-of naturally as the days shorten and temperatures decrease.

Bed inventory of the seedling crop at a bare root nursery requires a considerable effort. A crew of four to six will need perhaps a month to complete the field work; the necessary calculations will require another week or more. Inventory of a containerized crop is much simpler. Individual containers, instead of plots, serve as sampling units. If a good job of seeding was done, and germination was satisfactory, a relatively small number of samples should be needed to produce an estimate within the required limit of error. Even if unexpected variation necessitates an increased number of samples, inventory of a complete con- ainerized crop should require no more than two r three man-days.

Activity reaches fever pitch at a bare root ursery late in the year as lifting season begins. he labor crew has been built up to maximum size s seedlings are lifted, packaged, and stored or elivered. However, no special effort is necessary o package containerized seedlings; they may be ransported within the container in which they ere grown. Perhaps one or two additional laborers ay be needed for loading, but use of portable onveyor makes it possible for small crews to load ven refrigerated vans in a short time. The North arolina Division of Forest Resources has considered emoving the containerized seedlings from the con- ainers and transporting them in plastic bags to implify the transportation problem, but so far uch a practice has not been tried because of an- icipated labor costs.

A dependable pool of temporary labor is abso- utely essential to the successful operation of a ontainerized facility. A small permanent crew can end crops growing in the greenhouse or hardening- ff outside, but filling containers, seeding, and lacing seeded containers in the greenhouse require ore people. If containers must be assembled, abor needs are increased. In a summer crop pro- uction schedule, if the containers must be as- embled, a crew of three to six may be needed above d beyond the permanent crew for about three weeks t of the twelve weeks production period. This uctuating requirement for laborers causes a oblem. If the facility is near an urban area, ployemnt of teen-aged high school students may a solution. In a rural area, temporarily un- ployed farm laborers may be available. If ssible, locating the containerized operation close- a bare root nursery may ease the situation. tra laborers may be hired by the nursery and moved om one operation to the other as needed. Although re root production requires more laborers, the uctuation is more seasonal, *i.e*, a maximum crew ring winter, a reduced crew in the spring, and a nimum crew during the summer.

The North Carolina Division of Forest Resources has used all the methods listed above in an effort to solve the problem of temporary labor for the containerized operation. The best results have been obtained by hiring two temporary workers for the entire summer and filling the increased need at seeding time by borrowing people from other programs. The containerized facility is about thirty-five miles from the bare root nursery where laborers have been borrowed, and this travel distance reduces efficiency and increases cost. Assuring the availability of temporary labor when needed must receive the highest priority from the containerized nurseryman.

The flexibility inherent in containerized production allows coordination with field planting to a degree unheard of in bare root production. Crops can be timed to mature at the exact time when requested by the planters, or species can be changed with relatively short notice. Enough lead time must be allowed; the planters must realize that 16 or more weeks may be required to change to production of a species whose seed require stratification. Without stratification, production time from seeding to usable seedlings requires at least 12 weeks. Thus the flexibility in production has some limits.

No discussion of containerized production can be complete without some reference to natural disasters. Probably the most common disaster at a bare root nursery is heavy rains washing away the seeds following seeding, but the size of the fields and variation in the rainfall generally prevent a total failure. In containerized production, it seems that the accelerated biological process also mean accelerated possibilities for disaster. Power failure on a cold winter night might wipe out an entire crop; a power failure in late spring may result in excessive heat damage to a crop of cool climate seedlings; a hail storm may destroy a greenhouse and a crop in short order. The chance of losses as described above can be minimized; the containerized nurseryman should evaluate this potential for the area in which his facility is located and take steps to eliminate the chance of unacceptable damage.

What might be concluded from comparing experiences gained in working with both production systems? First, attention to even small details is of paramount importance in maintaining operational production of containerized seedlings. Forgetting the smallest detail can result in unacceptable losses or perhaps even the failure of an entire crop. The containerized production supervisor must impress upon all his staff the need for attention to what might seem to be the most insignificant detail.

The containerized nurseryman must anticipate problems and plan their solution in advance. These problems may be biological, mechanical, or involve human relationships. All three areas are of vital importance in containerized seedling production.

During the production phase, the pressure never lets up on the supervisor of a containerized operation. Because of the machinery involved, the greenhouse must be checked every day. If seed are in stratification, the seed must be turned periodically and the compressor checked. Towards the end of the production cycle, calls can be expected from the field planters. There is literally never a dull moment!

Containerized production does offer some advantages. The planting season can be extended to include all the summer and perhaps the fall, thus spreading out labor requirements. Seedling crops can be closely coordinated with the planters; crop production can be adjusted to utilize labor that may be available for short periods only. Production of various species can be adjusted on a relatively short term basis.

Probably the greatest disadvantage to containerized production is the high per unit cost of seedlings produced. Bare root southern pine seedlings can be produced for one-half or less the cost of containerized seedlings. Also, transportation costs are high, and logistic problems have been noted in providing seedlings to the planters. Lack of moisture may also adversely affect field survival.

Finally, containerized seedling production, particularly on a small scale, is both labor intensive and energy intensive. Such production should not be initiated unless it has been definitely established that the need for and the value of the seedlings produced justifies the capital investment and production costs that will be incurred.

LITERATURE CITED

Balmer, William E. and James C. Space.
1976. Probability tables for containerized seedlings. USDA For. Ser., Southeast. Area State and Priv. For., Atlanta, Ga. 25 p.

Space, J. C. and W. E. Balmer.
1977. Minimum cost calculation for container planting. USDA For. Ser., Southeast. Area State and Priv. For., Atlanta, Ga.

Tinus, Richard W. and Stephen E. McDonald.
1979. How to Grow Tree Seedlings in Container in Greenhouses. USDA For. Ser. Gen. Tech. Rep. RM-60, Rock. Mt. For. and Range Exp. Sta. Fort Collins, Colo. 256 p.

FULLY CONTROLLED OR SEMI-CONTROLLED
ENVIRONMENT GREENHOUSES--
WHICH IS BEST?1/

STEPHEN E. McDONALD2/

Abstract--The general method for deciding what kind of containerized tree seedling growing facility to construct is discussed. Biological, economic, and operational factors are incorporated in the logic together with product needs considerations.

INTRODUCTION

Suppose you are charged with the responsibility to develop a containerized tree seedling facility. How do you decide what kind of greenhouse structure, if any, is needed? In other words, what will be the most cost effective and operationally efficient production facility capable of producing the quality and quantity of trees needed? This is no simple question. Many container operations in the Pacific northwest have failed because, at the outset, the wrong type of facility was constructed.

For the purposes of this brief paper, I will not discuss site selection, market assessment, bare-root production alternatives, or several of the other factors of major importance to containerized tree nursery development. Rather, I will attempt to primarily address how to choose what kind of greenhouse facility to build.

THE RANGE OF ALTERNATIVES

In order to select the right kind of containerized tree seedling structure you have to know the range and general advantages of the alternative facilities. Three categories can be isolated: fully controlled environment (FEC), semi-controlled environment (SEC), and uncontrolled environment (UCE).

Essentially an FEC greenhouse is one that completely encloses the crop. Mechanical heating and cooling equipment keeps the inside of the greenhouse at near-optimium temperatures for the crop. The heating and cooling capability of the structure must be engineered for the climate of the location and the crop to be grown. Added equipment, such as electric lighting, carbon dioxide generators or humidity control, is added as justified.

The SEC greenhouse, on the other hand, is designed to only partially control the environment around the crop. These structures usually consist of a transparent roof with plastic side and end walls that can be removed or rolled-up. In the spring, or in unusually cold weather, the structure can completely enclose the crop. Supplemental heat can be added. Interrupted photoperiod lighting can also be installed. However, for most of the growing season the sides of the structure are open and cooling is by convectional movement of the air from the sides of the structure up through vents in the roof. The roof primarily serves to divert rainfall from the crop so irrigation and fertilization can be controlled.

The UCE growing facility (the term structure or greenhouse cannot be used) usually consists of an asphalt slab graded so excess water will drain from it. Usually shadecloth is stretched over the area, but not necessarily if the climate is cool and cloudy as it is in British Columbia. The blocks of containers may be placed on pallets on the ground or on pallets on sawhorses. Irrigation is often from a portable aluminum pipe system with impulse sprinkler heads on the risers.

1/ Paper presented at the Southern Containerized Forest Tree Seedling Conference, Savannah, Georgia, August 25-27, 1981.

2/ Forestation and Tree Improvement Specialist. Cooperative Forestry, Washington, D.C.

In some cases the actual germination of the trees takes place in a special structure designed for the purpose. In other cases it is done outside. Inclement weather is the big worry in a UCE container nursery operation.

Facilities have been developed that exist along an unbroken continuum from nearly completely automatic (FEC) greenhouses to very rudimentary (UCE) facilities. Each category has advantages and disadvantages:

1. Fully Controlled Environment Greenhouses (FEC).

   Advantages
   a. Full environmental control.
   b. Trees can be grown as rapidly as possible.
   c. Can be located just about anywhere.

   Disadvantages
   a. Costly to operate and build.
   b. Equipment must function properly.
   c. Energy intensive.

2. Semi-Controlled Environment Greenhouses (SEC).

   Advantages
   a. Medium-priced and relatively simple.
   b. Some environmental control.
   c. Protection from catastrophic loss due to weather.

   Disadvantages
   a. Must be put in a mild climate.
   b. Still requires a greenhouse structure.
   c. Must grow trees in spring and summer.

3. Uncontrolled Environment Facilities (UCE).

   Advantages
   a. Least expensive to build.
   b. Little equipment to maintain.
   c. Very low energy requirements.

   Disadvantages
   a. No environmental control.
   b. Requires a mild climate.
   c. Risk of catastrophic loss high.
   d. Must grow trees in spring and summer.

So the best production facility for you could be a fully controlled greenhouse or a uncontrolled facility or anything in between. How do you know what to choose?

WHAT IS NEEDED?

The size of tree seedling needed, integrated with the biological requirements of the tree species to be grown and the climate at the proposed site, provides the parameters for greenhouse design. More than one design alternative will probably be viable(Ekblad 1974).

Environmental Requirements

"Environmental requirements" refers to what a tree requires to successfully survive and grow. In a nursery we are obviously interested in rapid, normal growth and development. There are a number of interacting factors important in determining seedling growth rate and morphogenesis. These include temperature, light, moisture availability, nutrition, and humidity. Greenhouse structures and associated hardware can control all part of these. Temperature is probably the most important factor in determining growth rate, provided the others are at some reasonable level. This is basically because temperature has such a marked influence on biological chemical reaction rates. One way to show this is to describe the general interactions between photosynthetic rate, respiration rate, and net assimilation rate at different temperatures (Fig. 1). Respiration can exceed photosynthesis at very high temperatures the plant can actually "starve under high temperature stress. On the other hand at very low temperatures photosynthesis barely exceeds respiration, because the chemical reactions involved are so suppressed, and plant growth can be very slow. In the middle temperature ranges (from 25 to 35°C or 77 to 95°F for most temperate zone plants) the net assimilation rate is greatest and the most plant enery is available for growth. In general a combination of warm daytime and cooler nightime temperatures (lower respiration rates) are best for plant growth, but this varies widely depending on the adaptation of the species or ecotype within species.

Ideally the best day-night temperature combination of the crop should be known. In agronomic and horticultural crop production this is one of the major factors in determining where certain crops are grown. For tree seedlings Dr. Richard Tinus, of the USDA-Forest Service's Rocky Mountain Experiment Station, has developed growth chamber techniques for quickly determining the effects of various day and night temperatures on the growth of tree seedlings (Tinus 1977). He has done this for some timber species and has found optimum temperatures to vary considerably. The data is placed on contour graphs with day

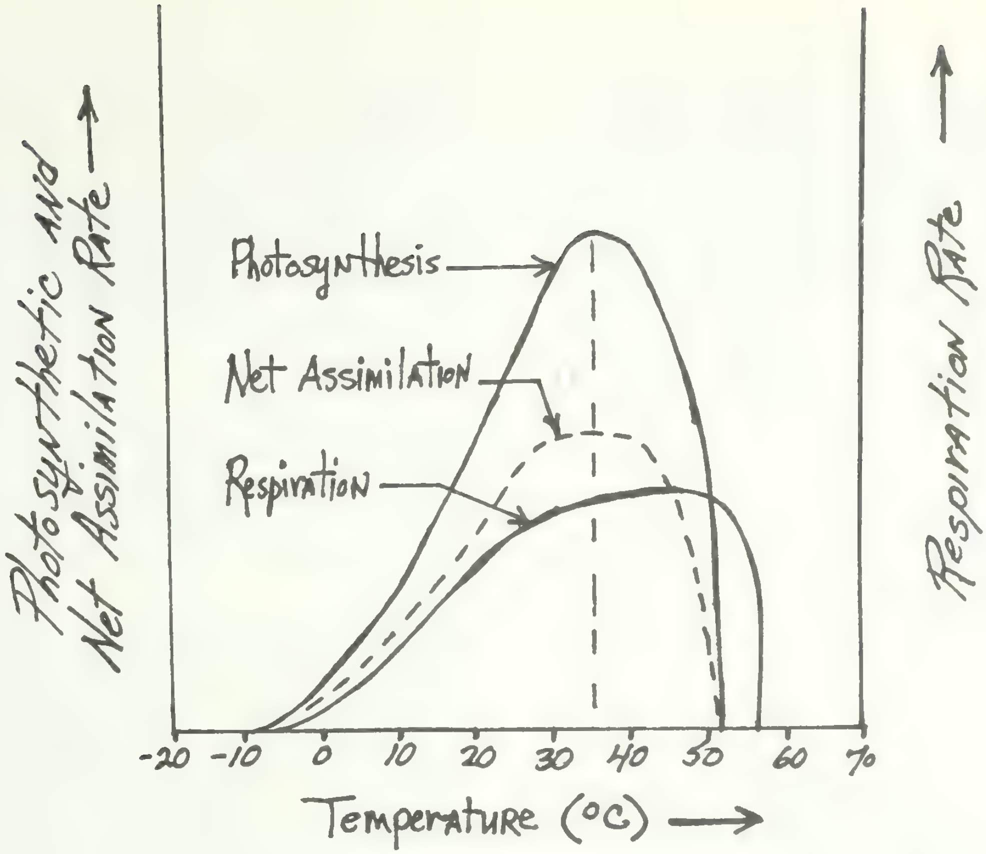

Figure 1.--Effect of temperature on biological chemical reaction rates.

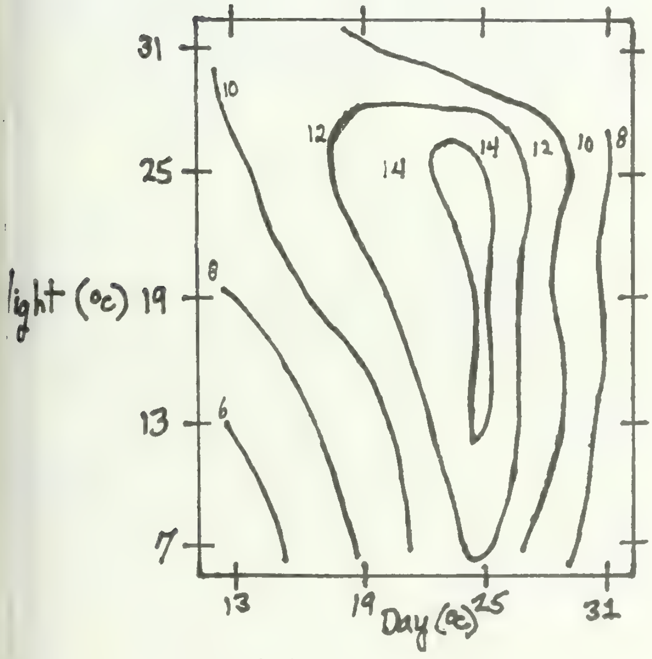

Figure 2.--Heights (cm) of ponderosa pine seedlings as a function of day and night temperature (From Tinus 1977).

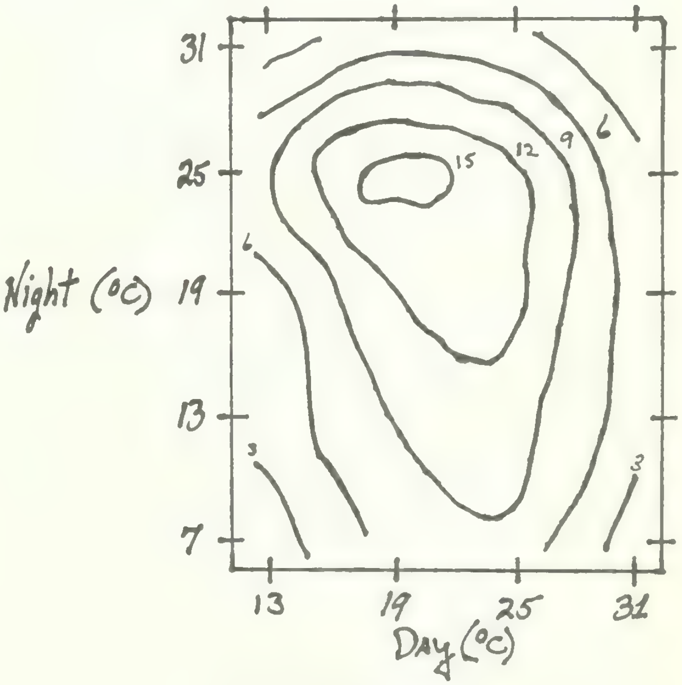

Figure 3.--Dry weights (gm) of ponderosa pine seedlings as a function of day and night temperature (From Tinus 1977).

temperature on the abscissa and night temperature on the ordinate An example is shown in figures 2 amd 3 for a Nebraska source of ponderosa pine (Pinus pondrosa Laws). The height and dry weight graphs are shown. These pine seedlings grew best at day temperatures near 25°C (77°F). However, night temperatures could vary from 15 to 25°C (59 to 77°) with little effect on height. Warm nights (25°C) definitely maximized dry weight accumulation. Graphs of other species, such as blue spruce, are quite different. All the graphs which exist for the various tree species are available in the manual "How to Grow Tree Seedlings in Containers in Greenhouses" (Tinus and McDonald 1979).

Such graphs do not exist for southern tree species. Approximations of suitable temperatures for greenhouse culture of southern pines do exist from past greenhouse experience. Such experience, accumulated by growing repeated crops in an FEC greenhouse, takes years to develop, whereas it can be done in growth chambers in a couple of months.

Where the temperature graphs are especially needed is when SEC or UCE facilities are being planned. These graphs, compared to weather data for a site can tell the planner if such facilities are practical. In both SEC and UCE facilities the temperature is primarily ambient air temperature. Consequently, for either of these types of facilities to be considered, you must have a mild climate where growing season temperatures approximate those suitable for tree growth. Under such circumstances excellent quality trees can be reared in SEC or UCE facilities, but this will normally always take longer and must be done during the growing season.

Once it has been determined that an SEC or UCE facility may be possible at a site, a pilot test is really needed to prove it is true. Then large-scale construction can begin on a firm basis.

Reliability and Operability Requirements

Reliability requirements pertain to assurance of production whereas operability requirements ments relate to design compatiblity with the operation of tree growing and shipment. If the organization or individual developing a containerized tree seedling production facility places a very high value on assured delivery, then reliability requirements will be very important. This will tend to make FEC facilities more attractive or, at the very least, will stimulate considerable study and pilot testing before an SEC facility is built It will also be more important to build reliability features into the structure type selected. Such items can include low and/or high temperature alarms and various other warning systems, redundant control systems, stationing a caretaker on-site, building security fences, etc.

In the Pacific northwest one producer which had successfully grown seedlings at a UCE facility for several years recently expanded the facility. However the expansion was into SEC structures. The reason was concern over the possibility of a catastrophic loss to bad weather.

In an FEC facility the mechanics of the greenhouse must be reliable. Malfunctions can result in rapid, disastrous environmental changes. In SEC units there is a degree of natural buffering in the system. Except in the early spring, where supplemental heat is called-for, an equipment failure can usually be tolerated for a little while.

Operability of a facility will depend on product and raw material flow. Such a system can be designed into the structure with varying degrees of intensity. If labor is cheap or variable (operating) costs of are less concern than inital capital costs, operability can be de-emphasized in the original design are planned for later retrofitting. On the other hand the facility can be designed for almost complete automation. The general wisdom is that the automation angle can easily be overdone, especially at the outset of a development. Certainly raw material and product flow should be designed into a facility at the start, but guard against over-investment in fancy hardware for moving things and minimizing labor until the needs are clearly focused by experience. The main idea is to be able to produce the seedlings needed at the proper time.

Cost Requirements and Considerations

Where the climate permits and slower production of a crop is acceptable, UCE and SEC facilities are very cost effective, especially if risk of loss to bad weather is discounted. However, the must be attuned to the tree species in question. Such facilities deserve real consideration in the south if the crop can be produced when desired.

Controlled environment greenhouses (FEC) are several times more expensive to build and operate than SEC or UCE units. The fast growth, seasonal timing of production and possibility of multiple crops in a year can make them more economic than other types of facilities.

When weighing cost requirements the developer should be mindful of the need of assured production initially. An FEC greenhouse will produce.

Experimentation with SEC growing methods can take place at a site after it is in limited production with an FEC unit.

A word of warning regarding greenhouse accessory hardware purchase is worthwhile at this point. One the major pitfalls in containerized tree seedling nursery development is a preoccupation with mechanical and engineering aspects of the project to the detriment of sound economic and biological reasoning. Consequently, a developer of a container tree seedling nursery should constantly ask two questions:

1. Is this item of hardware required to meet the environmental requirements of the crop?
2. If not, will it save enough labor, maintenance, or other expense to justify its purchase price?

Reconciliation of Requirements

The requirements for the facility--environmental, reliability, operability, and cost--are what define the problem of facility design and allow generation of viable alternative solutions. The alternative solutions will have variability in characteristics (cost, fuel requirements, assurance of production, etc.) that can be rated according to relative importance. Summation of these ratings will indicate the most desirable alternative if the ratings are carefully done. Existence of similar successful facilities in an area can affect the choice considerably. If an existing facility in the area is successful and of the type desired, major construction can usually begin without a pilot test. If no such facilities exist, a pilot test for evaluation is highly recommended. During such an evaluation process it is important that the best possible advice and help be acquired so that later major construction is based on pilot test information that truly represents what will happen in the expanded facility.

THE FINAL DECISION

The answer to the question--"Which is better fully controlled or semi-controlled greenhouses?" --depends on the developer's goals and circumstances. In other words the requirements can be isted, categorized, and ranked as to relative mportance. These elements can then be compared to he viable construction alternatives for the given ite/ species/delivery date combination existing. he best construction alternative can then be elected. With that sort of decisionmaking sequence outlined the selection job should be easy-ight? Wrong! Even if all the facts about facility requirements and facility construction alternatives re carefully quantified, you, as a developer, must still guage the politics of the situation. A facility of type "A" may be economically and biologically the most cost effective. However, it may not be the best alternative if the company or agency will not accept its appearance or the risk of crop loss associate with it. Facility "B: may be less efficient or more expensive but still be the better selection considering those other factors.

LITERATURE CITED

Ekblad, Robert B.
1974. Systems engineering for greenhouse operations. p. 260-265. In Proc. No. Amer. Containerized Forest Tree Seedling Symp., Great Plains Agric. Comm. Publ. 68, 45p. (Denver, Colo. Aug. 1974)

Tinus, R.W.
1977. Operating a greenhouse container nursery. In Proc. West. Gulf. Indep. Tree Improv. Assoc. Meet. (Alexandria, La., June 1977)

Tinus, R.W., and S.E. McDonald
1979, How to grow tree seedlings in containers in greenhouses. USDA-Forest Service Gen. Tech. Rpt. RM-60. 256p.

CAPITAL INTENSITY AND ECONOMIES-OF-SCALE FOR DIFFERENT TYPES OF NURSERIES[1]

Richard W. Guldin[2]

Abstract.--Average annual capital costs are estimated for 24 combinations of types of nurseries and seedling containers in 3 southern climatic zones. The optimal nursery expansion strategy is identified and compared with building a new bare-root nursery on a total-cost-per-1,000-seedling basis. The initial construction cost of a new container nursery and its implications for the entire reforestation program are discussed.

The South's Third Forest report (Southern Forest Resource Analysis Committee 1969) called for regenerating 30 million unproductive acres to pine by 1985. This need is in addition to reforesting productive land recently harvested. The report also called for having 60 million acres forested with genetically improved stock by the year 2000. The annual rate of regeneration by direct seeding and planting on all land-including idle farmland, forest land understocked with pine, unproductive upland sites converted to pine, and recently harvested land promptly regenerated--has not exceeded 1.6 million acres since the Third Forest report was issued 12 years ago. Present regeneration rates are barely achieving half the Third Forest goals. Twice as many seedlings are needed. All should be from genetically improved seed.

A major bottleneck to achieving the goal is inadequate nursery capacity. Finding suitable nursery sites and building new nurseries is expen-ive. Just the construction costs for 2 new indus-rial bare-root nurseries that began production in 1980 were $1 million and $2 million for annual out-uts of 18 and 25 million seedlings respectively. hese construction costs are equivalent to $56-$67 er 1000 seedlings annual production capacity ex-luding land. These 2 nurseries added only 6 percent to total southern nursery capacity. Applying hese costs, it would require an additional $55 million to double existing nursery output, assuming that suitable nursery sites are already owned.

Building new container seedling nurseries could help meet the seedling need. But are they economical? This paper estimates the cost of building new container seedling nurseries and compares the cost to that of building new bare-root nurseries.

NURSERY ALTERNATIVES

Four container nursery alternatives were developed for cost analysis by combining the favorable features and eliminating the unfavorable features of the 6 pilot-scale container nurseries in the South. The container nursery alternatives are identified by the type of seedling germination house used: (1) glass greenhouse, (2) fiberglass greenhouse, (3) timber truss greenhouse, and (4) pole shadehouse. These are alternatives to building new bare-root seedling nurseries. Cost comparisons between bare-root and container nursery alternatives will be made.

The cost of each nursery is influenced by a number of assumptions. Biological assumptions will be addressed in the discussion of each nursery. Several cost estimation assumptions are common to all 5 alternatives.

All capital costs were based on price quotations from nursery equipment manufacturers and wholesalers, or on actual bids for recently constructed facilities across the South. Locally available construction materials were priced at retail outlets in the New Orleans, Louisiana, area. Contingency factors were included. All costs were on a January 1, 1980, basis. An interest rate of 10 percent was used to amortize investments in facility components.

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Labor costs were based on man-hours of labor required to perform tasks at existing nurseries, multiplied by standard wage rates of $6, $8, and $10 per hour for unskilled, skilled, and supervisory labor categories. An additional 15 percent of total wages was added for the employer's share of social security, workmen's compensation, and unemployment insurance, based upon Louisiana rates for new nursery businesses.

The quantities and costs of goods and services used to produce seedlings were based upon amounts required by facilities currently in operation and prices quoted by their suppliers.

Direct overhead costs of the nursery operation were included in the total cost estimates. However, no factor was added to any alternative for general administrative expenses of higher echelons of the firm or agency.

Container nursery alternatives

Three major factors must be analyzed before cost estimates can be developed for a container seedling nursery: location of the nursery, type of nursery germination house, and the type of container. Nursery location and type of germination house jointly determine the number of seedling rotations that can be germinated annually in each house. The type of container and the size of the germination house jointly determine the number of seedlings grown per rotation. Thus, all 3 elements together determine annual seedling output as well as influence costs.

Nursery Location

Contrary to the bare-root nursery siting dictum that a site should be chosen which is as far north as possible to lengthen the seedlings' dormant period, container seedling nurseries should be located as far south as possible to maximize the frost-free growing period and minimize wintertime utility consumption. The number of rotations grown annually and output both increase as the length of the growing season increases. Higher outputs spread annual capital costs over a larger number of seedlings.

The South was divided into 3 climatic zones based on the length of the frost-free growing season and the incidence of daily air temperatures exceeding 90 degrees F (fig. 1). Seedling production schedules used in this study assumed that properly hardened seedlings would not be outplanted before the mean date of last frost in the spring nor later than 1 week before the mean date of first frost in the fall. Production schedules also assumed that seedlings could not be consistently outplanted during midsummer because of soil moisture and surface temperature limitations. The climatic criteria used to define the zones were:

	Frost-free length of growing season	Days when daily maximu air temperature exceed 90 degrees F
	-------No. of days-------	
Zone A	260-310	60-120
Zone B	215-245	60- 90
Zone C	185-215	30- 60

Within any zone, microclimatic conditions may alte actual production schedules and potential seedling outputs.

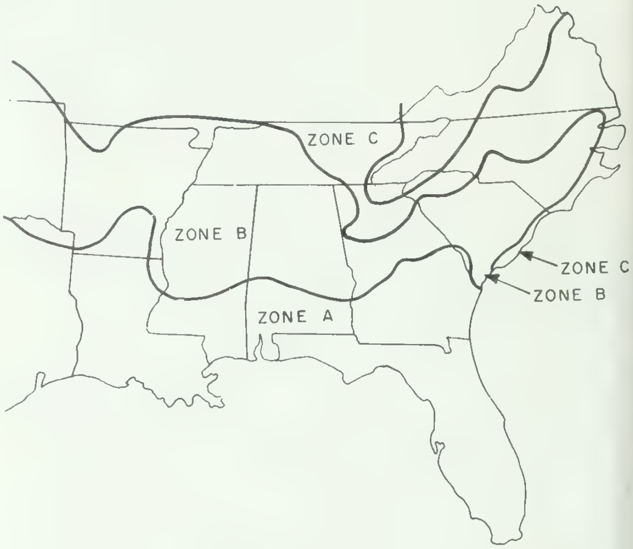

Figure 1.--Southern climatic zones.

Germination Houses

A container seedling nursery requires space i buildings to perform 3 basic functions: filling co tainers with media and sowing seed; seed germinati and initial seedling growth; and hardening seedling off prior to outplanting. Although one building could be used for all 3 functions, production efficiency increases if separate buildings are availabl that specialize in each function. A headhouse provides container filling and seed sowing space. Germination and initial seedling growth can occur i either a greenhouse or a shadehouse. Hardening off is most efficiently performed in a shadehouse. Because similar headhouses and shadehouses are used with different germination houses, specifying the type of germination house in this paper identifies the type of nursery.

The 4 types of container seedling nurseries (and germination houses) share several common features. Some of these are biological assumptions, an some induce commonality for cost comparison purpose The common features are:

Each nursery "replicate" (smallest efficient production unit) has 1 headhouse, 5 greenhouses for germination and 5 shadehouses for hardening off. An exception is the pole shadehouse nursery, which has 1 headhouse and 6 pole shadehouses for both germination and hardening off.

Sufficient CCA type C treated southern pine pallets to fill each greenhouse and shadehouse are included in building construction costs.

Loblolly or slash pine seedlings are grown in 12 to 16 week rotations.

One "greenhouse rotation" is equivalent to 3,240 square feet, ± 2 percent, of usable growing space. Greenhouse sizes were selected to provide this much usable growing space per house, assuming that 67 percent of the gross floor space was usable. Widths of greenhouses currently manufactured were assumed, and greenhouse length was adjusted to provide the usable growing space. Multiplying container cell densities per square foot by the usable growing space per rotation yields the total number of cells per rotation.

Ninety-five percent of the cells produce plantable seedlings. Sowing 2 seeds per cell, thinning and transplanting excess seedlings to vacant cells has attained this percentage of plantable seedlings in existing southern container seedling nurseries. Labor costs include these activities.

One "greenhouse rotation" per week is the maximum headhouse capacity.

Only one-half acre of land is needed for each building. Suitable land with adequate water supply should cost no more than $500 per acre.

Glass Greenhouse Nursery.--A glass greenhouse ursery has a wood-frame headhouse 40 x 60 feet, ontaining the nursery office, media-mixing, ontainer-filling, and seed-sowing equipment, stor-ge, lavatories, and main utility service station. forklift truck for pallet handling is included. ach of the 5 gable-roofed, aluminum-framed, glass-lazed greenhouses is 42 x 120 feet. The green-ouses contain complete and fully automated heating, ooling, carbon dioxide enrichment, and lighting ystems, an overhead crawling waterer with fertil-zer and chemical injector, all utilities and con-ections, including a telephone alarm system. Each f the 5 pole shadehouses is 44 x 240 feet. They re constructed of shadecloth stretched over a nylon ope grid supported by 3 rows of CCA type C treated oles. Irrigation is the only environmental control rovided in the shadehouses. Each shadehouse pro-ides sufficient space for 2 greenhouse rotations hile hardening off seedlings prior to outplanting. he shadehouses function as a "surge bin" between eenhouse production and field planting. The total nstruction cost of this nursery replicate is 96,500, which is equivalent to an annual fixed st of $78,993.

Fiberglass Greenhouse Nursery.--The same type of headhouse used for the glass greenhouse is used here. Each of the 5 fiberglass-sided greenhouses has a double bowed and trussed roof covered with 2 layers of ultraviolet resistant polyethylene sheeting, held apart by air pressure from a small blower. Each greenhouse measures 34 x 150 feet. The greenhouses contain the same climate control equipment as the glass greenhouse, except for the irrigation system. This greenhouse has a solid-set plastic pipe irrigation system buried in the floor, with threaded removable risers. A fertilizer and chemical injector is provided. The 5 pole shadehouses used for hardening off are of the same construction as the glass greenhouse nursery, but each measures 36 x 300 feet. The total construction cost of this facility is $295,691, which is equivalent to an annual fixed cost of $42,763.

Timber Truss Greenhouse Nursery.--Because annual seedling production levels are lower for this type of greenhouse than the previous 2, less expensive partially-mechanized media-mixing, container-filling and seed-sowing equipment is used in the headhouse. A forklift truck is still included. Timber truss greenhouses measure 34 x 150 feet. They are constructed onsite from standard softwood dimension lumber and poles. Timber trusses are constructed from 2 x 6 lumber to a 4 over 12 pitch using half inch plywood gussets. The trusses are set on 4-foot centers atop two pole walls 34 feet apart. The pole walls are constructed of 4-inch diameter CCA type C treated poles with a double 2 x 4 top plate. The trusses are tied together with sufficient 1 x 4 lumber to make the structure wind-firm for the locality, and covered with a layer of 2-inch galvanized poultry mesh and a single layer of 6 mil ultraviolet resistant polyethylene sheeting. Only irrigation and photoperiod control equipment are provided in the timber truss greenhouse. The pole shadehouses used for hardening are identical in size and construction to those for the fiberglass greenhouse nursery. The total construction cost of a timber truss greenhouse nursery is $167,309. The annual fixed cost is $31,172.

Pole Shadehouse Nursery.--The same type of headhouse used for the timber truss nursery is used for the pole shadehouse nursery. The construction and size of the shadehouses used for germination are identical to those used for hardening in the glass greenhouse nursery. This type of nursery is the least expensive to construct, but provides the least climatological control. Only irrigation is provided in this nursery. The total construction cost of this nursery is $122,608, or an annual fixed cost of $20,925.

Types of Containers

Four types of containers were considered in the study: No. 2 Styroblocks, Kys-Tree-Starts, and 2 sizes of Spencer-Lemaire Rootrainers, Fives and Ferdinands (table 1). The purchase price of the containers, container reusability, and labor requirements for container assembly, filling and sowing, are the 3 factors that affect the cost of containers in growing seedlings.

Table 1.--Physical characteristics and production cost components

Type of container[1]	Cell density	Seedling density	Average cost of labor and materials	Average capital cost of container
	---No./square foot---		---$/1000 seedlings---	
Kys-Tree-Start	150	142	35.83	0.00
Spencer-Lemaire Fives Rootrainers	82	78	22.61	13.56
Spencer-Lemaire Ferdinand Rootrainers	118	112	20.61	8.48
Number 2 Styroblocks	96	91	17.87	2.38

[1] The use of trade, firm, or corporation names in this paper is for the information and convenience of t reader. Such use does not constitute an official endorsement approval of the product by the U.S. Dep. Agric. to the exclusion of others which may be suitable.

The No. 2 Styroblocks and the Spencer-Lemaire Rootrainer trays (both sizes of Rootrainer cells use the same tray) could be used for 6 rotations. Both the Fives and Ferdinand Rootrainer cells last only 2 rotations. These lifetimes, based on actual use in southern nurseries, were used to adjust the container purchase price to a container capital cost per 1000 seedlings produced. The container cost per 1000 seedlings enters capital cost calculations along with nursery construction costs. Because Kys-Tree-Starts cannot be reused, their purchase price remains in the labor and materials category and does not enter capital cost calculations.

The Spencer-Lemaire Rootrainer "books" must be folded to form strips of cells which are then inserted into the Rootrainer tray. Seventeen Ferdinand books fill the tray with 102 cells, compared to 13 Fives books that provide only 65 cells. In addition, the trays themselves must be assembled. Neither of the other 2 kinds of containers requires assembly. More media is required per 1000 cells for the Fives Rootrainers, 3.5 cubic inches, per cell, than for the 2.5 cubic inch cells of both the Ferdinand Rootrainer and the No. 2 Styroblocks. The Kys-Tree-Start container is made of molded peat, so requires no assembly, nor media. Only labor for seeding is required. Where Kys-Tree-Starts are used, headhouse capital costs can also be reduced because no media-mixing or container-filling equipment is needed.

Analysis of the cost and operations records of existing container seedling nurseries in the South reveals that labor and materials costs are determined primarily by the type of container selected. The labor and materials cost of a single rotation is independent of the type of germination house and is affected only slightly by the level of headhouse mechanization. The labor and materials component of producing a rotation of seedlings in the various containers was separated from the capital cost component owing to the container purchase prices (table 1). Annual lab and materials costs were divided by annual seedl output to estimate the average labor and materia cost per thousand seedlings.

Bare-Root Nursery

Bare-root seedling costs also have a capita component and a labor amd materials component.

Capital Costs

Capital costs for a new bare-root nursery f into 3 categories: land acquisition and site pre ration, construction of nursery buildings, and p chase of equipment.

Wakeley (1954) outlined the quality and qua of land required for new bare-root nurseries. H recognized that the best nursery sites are often high-quality agricultural land. A high price is quired to bid such land away from crop productio Land costs should include not only the purchase price of the land, but also the cost of the sear process and closing costs. If land for the nurs is already owned by the firm or agency, its cost the net benefits foregone from the prior land us In addition, if the site selected is not optimal but the best owned by the firm or agency, there an opportunity cost involved in settling for a s optimal site. Following Wakeley, this study ass that 3.5 acres would be needed for beds, paths, roads, and administrative areas for each million seedlings annual capacity.

Once acquired, the acres to be used for see ling production must be cleared and leveled, bed laid out, and an irrigation system installed. A green manure crop or other soil management pract may be needed to build up the soil prior to producing the first crop of seedlings.

While site improvements, such as the irrigation system, have an assumed 20 years lifetime, the inherent land value is assumed constant in perpetuity. Therefore, land acquisition costs must be converted to an annual value using the formula for a perpetual annual series rather than a terminable annual series. Costs for land acquisition and site improvements were converted to a basis of annual cost per million seedlings annual capacity basis. When the resulting average capital cost ($3,177 per million seedlings annual capacity) is multiplied by nursery size, annual land capital cost is estimated.

The buildings required are a nursery office, equipment storage and repair garage, a packing building, and a refrigerated seedling storage warehouse. The sizes of the nursery office and equipment garage do not vary as seedling production levels rise, but the sizes of the packing building and refrigerated warehouse do vary with output. All buildings are assumed to have a 20-year life. The cost of buildings by output ranges are:

Million seedlings annual output	Total annual cost of buildings
1.0- 9.9	$13,975
10.0-14.9	$21,046
15.0-19.9	$28,117
20.0-24.9	$38,723
25.0-29.9	$49,330

Equipment required by the nursery includes one or more pickup trucks, tractors, sprayers, seedling lifters, forklift trucks, and wagons. Nurseries producing less than 6 million seedlings have the least amount of equipment. From 6 to 10 million seedlings annual production, equipment costs rise rapidly as production becomes more heavily mechanized. In addition to more equipment, equipment size also increases. Both factors increase equipment costs. Above outputs of 10 million seedlings annually, costs increase at a diminishing rate, due to economies of scale. Both depreciation and operating expenses are included in the equipment costs:

Million seedlings annual output	Total annual cost of equipment
1.0- 5.9	$19,936
6.0- 6.9	$23,923
7.0- 7.9	$27,910
8.0- 8.9	$31,897
9.0- 9.9	$35,885
10.0-14.9	$39,872
15.0-19.9	$43,859
20.0-24.9	$47,846
25.0-29.9	$51,834

Labor and Materials Cost

Cost records for the U.S. Forest Service's J. W. Ashe Nursery were examined. After subtracting capital depreciation, regional office overhead, equipment use, and the costs of the seed extractory, the remaining cost was divided by annual output. The resulting cost, $19.07 per thousand seedlings, includes all labor, salaries, office expenses, seed, fertilizer, pesticides, packing supplies, and other miscellaneous materials essential for nursery operations. This cost is typical of existing southern bare-root seedling production (Guldin 1982).

DISCUSSION

The cost comparison proceeds in 2 steps. First, the most cost-efficient container seedling nursery is developed by selecting the most cost-efficient container seedling nursery and nursery expansion strategy from the 48 possible combinations of containers, germination houses, and climatic zones. Then, the most cost-efficient container seedling nursery is compared to the cost of building a new bare-root seedling nursery over a range of seedling outputs from 1 to 20 million seedlings annually. Finally, the capital cost implications of choosing between containerized and bare-root seedling nurseries is examined.

Choosing Among Container Nursery Options

Seedling production cost, exclusive of the cost of buildings and equipment, is the sum of columns 3 and 4, Table 1.

Type of container	Seedling production cost per 1000 seedlings
Spencer-Lemaire Fives Rootrainers	$36.17
Kys-Tree-Starts	$35.83
Spencer-Lemaire Ferdinand Rootrainers	$29.09
Number 2 Styroblocks	$20.25

The seedling production costs of the first 2 containers are nearly double the $19.07 production cost of bare-root seedlings. They will not be discussed further. The remaining 2 containers have the same cell volume, Table 1, and bracket the 100-cells-per-square-foot optimal density level (Barnett and McGilvray 1981).

The annual capital cost per 1000 seedlings is the sum of column 4, Table 1, for the appropriate container and the annual capital cost of the nursery buildings, land, and equipment. The annual capital cost per 1000 seedlings has been graphed over an annual nursery output range from 1 to 20 million seedlings for each climatic zone and nursery type (figs. 2-4). The sawtoothed discontinuities result from the cost of adding 1 new headhouse, 1 germination house, and 1 hardening house to the most efficient nursery replicate. Costs rise because 80 percent of the new headhouse's container-filling and seed-sowing capacity is not utilized if only 1 germination house is added. Although the headhouse does not directly affect seedling output, excess headhouse capacity increases cost. Adding a minimum of 2 germination houses with a new headhouse lowers the nursery's average annual capital cost per 1000 seedlings considerably.

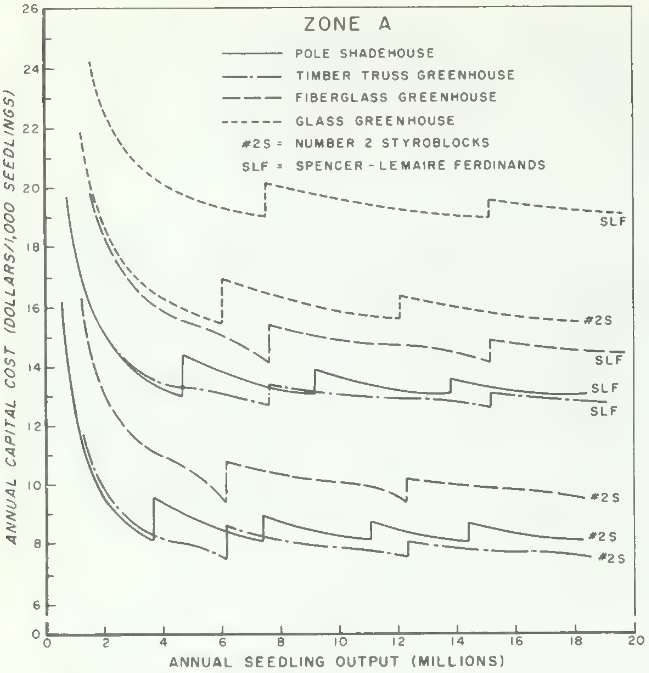

Figure 2.--Nursery annual capital costs in zone A.

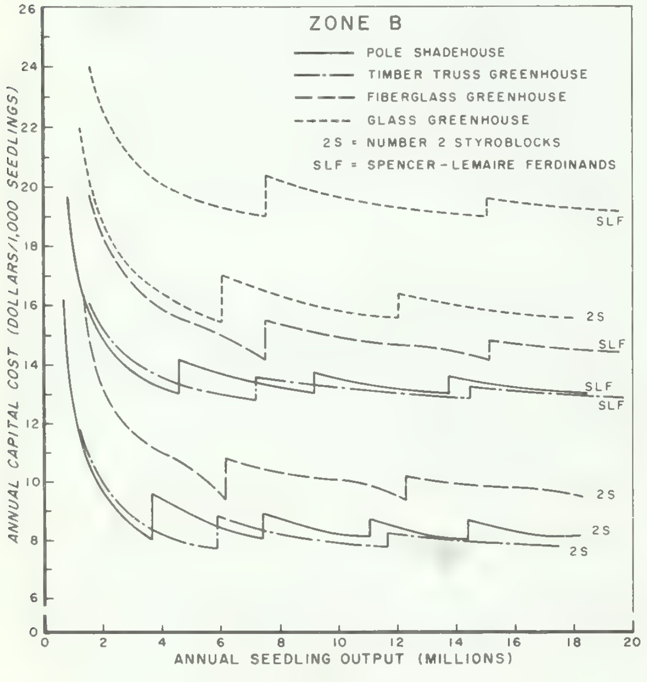

Figure 3.--Nursery annual capital costs in zone B.

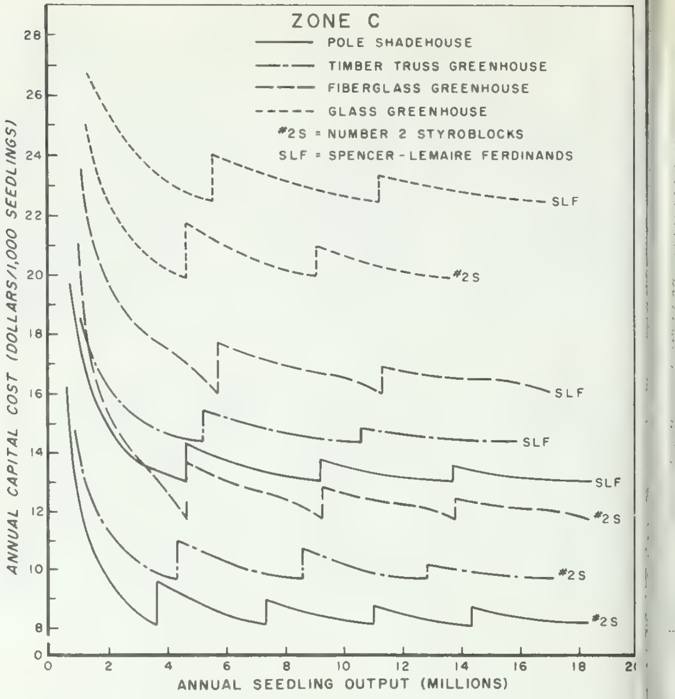

Figure 4.--Nursery annual capital costs in zone C.

Selecting the most cost-efficient type of nursery only requires analyzing average annual capital costs per 1000 seedlings (figs. 2-4) because the average cost of labor and materials for seedling production (table 1, column 3) does not vary with the type of nursery. The pole shadehouse and timber truss greenhouse nurseries have the lowest average annual capital costs per 1000 seedlings ($7.50 to $8.50 per 1000 seedlings) in all 3 clima ic zones. Although the fiberglass and glass green house options offer greater control of the seedli growth environment, the increased production from these 2 options is insufficient to reduce average capital cost per 1000 to the pole shadehouse or ti ber truss greenhouse levels. If a controlled envi ronment is required, the fiberglass house is clear less expensive. However, the cost disparity betwe the fiberglass greenhouse and the 2 lower capital cost options suggests that multipurpose nurseries, combining progeny testing or other research with mass production of seedlings for reforestation, ar cost-inefficient. If a highly-controllable enviro ment is desired, a greenhouse could be built separately from the houses used for mass production o regeneration seedlings. The fiberglass option should not be chosen for the entire reforestation nursery when only limited research space is neede High-capital greenhouses are not essential in the South to produce quality reforestation seedlings.

The pole shadehouse nursery has the lowest average annual capital cost per 1000 seedlings ove the entire output range in zone C (fig. 4). Howev the choice of the most cost-efficient type of nurs ery in zones A and B depends upon nursery size. For No. 2 Styroblocks, a pole shadehouse nursery h the lowest cost up to 3.7 million seedlings annual and between 6 and 7.5 million seedlings annually. For Spencer-Lemaire Ferdinand Rootrainers, a pole shadehouse nursery is the least expensive option u to 4.6 million seedlings annually and between 7.3 and 9.2 million seedlings annually. In the low ou put ranges for both containers (up to 3.7 million and 4.6 million seedlings respectively), the pole shadehouse option offers minor cost savings--5 cer to 30 cents per 1000 seedlings. In the higher output ranges for both containers (6-7.5 and 7.3-9.2

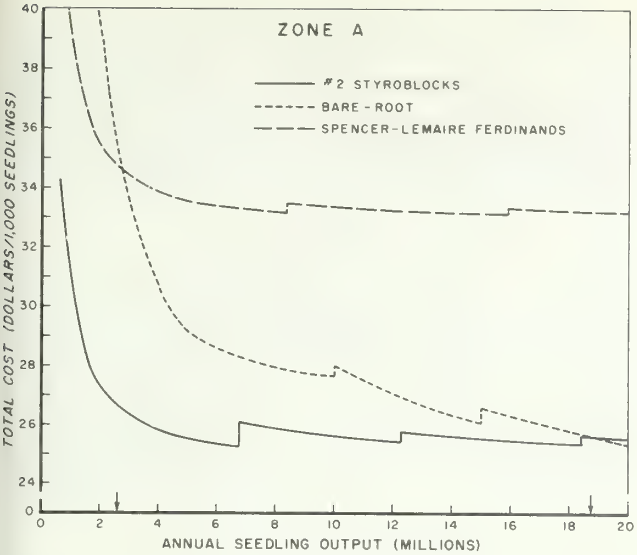

Figure 5.--Seedling total cost in zone A using the optimal container nursery expansion strategy.

million seedlings respectively), the pole shadehouse option is less expensive because an inefficient increase in production level results from adding only 1 timber truss greenhouse to the second headhouse. In these higher output ranges, the pole shadehouse uses available headhouse capital more efficiently. Pole shadehouse savings in these higher output ranges only amount to 10 cents to 40 cents per 1000 seedlings.

These minor cost savings and efficient output ranges for both containers suggest that the most cost-efficient nursery expansion strategy is to combine the pole shadehouse and timber truss greenhouse options through staged construction as seedling requirements rise. The strategy at low nursery output levels is to construct 1 headhouse and up to 6 pole shadehouses for germination. Then, as seedling requirements increase, timber truss greenhouses are added, converting the pole shadehouses from germination houses to hardening houses. Up to 5 timber truss greenhouses could be added before another headhouse is needed. The total cost of growing seedlings using this strategy was calculated and graphed for both types of containers (figs. 5-7).

Most container seedling nurseries presently operating in the South produce between 400,000 and .5 million seedlings annually. They are operating n the steeply sloped region of the cost curves. The steepest portion of the curves ends between 2.5 and 3 million seedlings annual output. Existing nurseries will find their marginal cost per 1000 seedlings drop due to increasing returns to scale as outputs are increased to the 3 million seedling threshold. Scale economies derive chiefly from more efficient headhouse utilization. New container seedling nurseries should have annual outputs greater than 3 million seedlings to benefit from economies of scale.

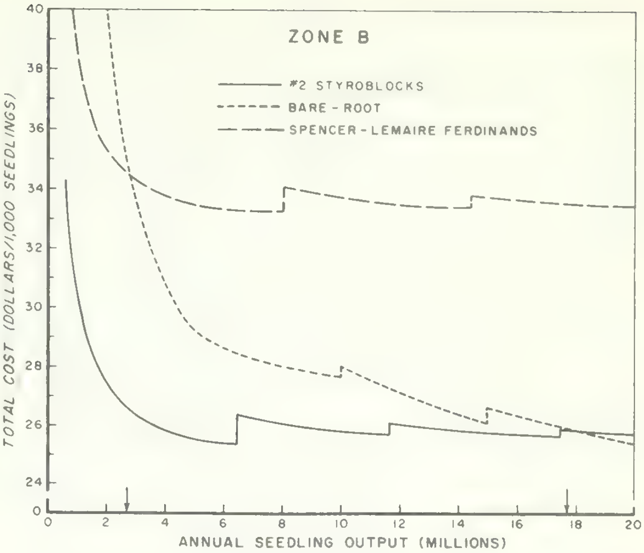

Figure 6.--Seedling total cost in zone B using the optimal container nursery expansion strategy.

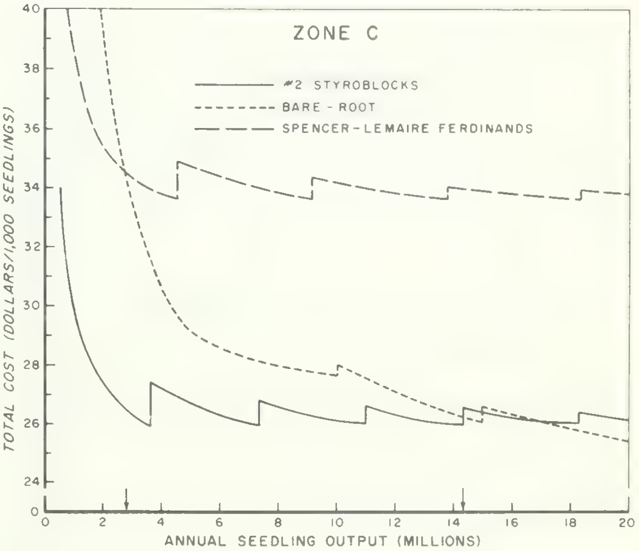

Figure 7.--Seedling total cost in zone C using the optimal container nursery expansion strategy.

Comparison of Container and Bare-Root Nursery Costs

The total cost of growing bare-root seedlings in a new nursery including all capital costs, was calculated and graphed in figures 5-7. Past comparisons of costs for bare-root and container seedlings have been between bare-root nurseries producing 15 to 30 million seedlings annually and container nurseries one-tenth the size. Equitable comparison requires that both types of nurseries must be the same size.

A container nursery using No. 2 Styroblocks can produce seedlings at a lower total cost than a new bare-root nursery of equivalent size for annual seedling outputs of less than 14.3 million in zone C and below 18.7 million in zones A and B. Spencer-Lemaire Ferdinand Rootrainer seedlings are less expensive than growing bare-root seedlings in a new nursery for annual outputs less than 2.6 million seedlings in all zones.

The slopes of the styroblock and bare-root seedling curves are so flat in the area of their intersection that for 2 million seedlings on either side of the intersection, costs vary by 30 cents per 1000 seedling (1 percent) or less. This cost variation is within the presumed margin of error in cost estimation. Hence, in the 4 million seedling output range, bare-root and No. 2 Styroblock seedling costs are essentially equivalent. Under the prevailing cost accounting practices employed by public nurseries, No. 2 Styroblock seedlings could be sold for the same price as bare-root seedlings.

Capital Cost Considerations of Choosing the Type of Nursery

The initial construction cost of a new nursery is not portrayed in figures 2-7. Yet, in an era of high interest rates for private firms and tightening public agency budgets, the level of initial construction costs should be considered. Capital expenditures are often more closely monitored than operating budgets, which may be increased automatically each year via cost-of-living or price adjustment indices.

Capital expenditures for an 18 million seedling per year container seedling nursery constructed in zone B are:

4 headhouses @ $44,240	$176,960
16 timber truss greenhouses @ $11,608	185,728
16 pole shadehouses @ $12,204	195,264
18 acres of land @ $500 (per acre)	9,000
322,750 No. 2 Styroblock "quarterblocks" @ $0.65	209,788
Total	$776,740

This initial construction cost is equal to $43.15 per 1000 seedlings of production capacity. Although this is a relatively inefficient output level (there is only 1 germination house for the fourth headhouse, fig. 6), $43.15 is still nearly $13 less than the $56 per 1,000 seedlings of-production-capacity cost for a recently constructed bare-root nursery in the South. Instead of needing $55 million dollars to meet Third Forest seeding requirements, container seedling nurseries could double seedling output for $38 million.

Also, once constructed, the container facilities would cost $1.20 per 1000 seedlings less to operate.

The $56 bare-root cost does not include land purchase, which could add another $15 to $20 per 1000 seedlings annual capacity to initial capital costs. A public agency forced to purchase land f a new nursery could save between $250,000 and $500,000 or more in initial costs on an 18 millio seedling nursery by opting for a container nurser rather than a new bare-root one.

Two additional problems may arise resulting from large increases in seedling production, whet r from a container or a bare-root facility--capital investments and labor availability for site preparation and planting. Eighteen million seedlings will plant 24,800 acres at 6 x 10 spacing. The capital required for site preparation and plantin machinery may exceed nursery capital requirements Capital requirements for all components of the reforestation process must be jointly considered to arrive at the best decision.

Year-round planting capabilities of containe grown seedlings may create site preparation scheduling problems. Instead of taking nine months to prepare sites for a three month bare-root plantin season, site preparation would probably be performed continuously to keep ahead of planting dur an 11-month planting season (3 months planting ba root seedlings augmented by an additional 8 month planting container-grown seedlings). Site prepar tion and planting will become year-round tasks fo company personnel or local contractors rather tha a temporary and intermittant job performed for sh periods. If planting contractors migrate followi spring warming trends, sufficient local planting labor may not be available for the rest of the se son and need to be developed. Labor availability for site preparation and planting should be carefully examined. It may take longer to find and train quality workers for these tasks than it tak to construct a container nursery and produce the first crop to seedlings.

CONCLUSIONS

Seedlings for reforestation can be grown as inexpensively in containers as in a new bare-root nursery. The optimal nursery development strateg in climatic zones A and B is to use pole shadehous for germination if less than 6 million seedlings a needed. When larger quantities are needed, add timber truss greenhouses for germination and conve the pole shadehouse to hardening houses. In zone using pole shadehouses for germination is the best strategy at all production levels. These low-capital germination houses are the most cost-efficient for southern growers. High-capital germ nation houses do not boost output enough to pay.

The minimum nursery size that captures the majority of economies of scale is 2.5 to 3.0 milli seedlings annual output. Below this production level, headhouse capital is underused. Full emplo ment of headhouse machinery dicates the efficient production range of the nursery.

Site preparation and planting capabilities may ultimately restrict nursery size or output levels. Considerably more capital may be needed to raise site preparation output levels than is needed for nursery establishment. Capital and labor requirements for the entire reforestation program must be coordinated and examined as a total package.

LITERATURE CITED

Barnett, James P., and John M. McGilvray.
1981. Container planting systems for the South. U.S. Dep. Agric. For. Serv. Res. Pap. SO-167, 18 p. South. For. Exp. Stn., New Orleans, LA.

Guldin, Richard W.
1982. Nursery costs and benefits of container-grown southern pine seedlings. South. J. Appl. For. (forthcoming).

Southern Forest Resource Analysis Committee.
1969. The South's Third Forest: How it can meet future demands. South. For. Res. Anal. Comm. New Orleans, LA. 53 p.

Wakeley, Philip C.
1954. Planting the southern pines. Agric. Monogr. No. 18. U.S. Dep. Agric. For. Serv. 233 p.

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PRACTICAL GUIDELINES FOR DEVELOPING CONTAINERIZED NURSERY PROGRAMS[1]

Philip F. Hahn[2]

Abstract.--Practical guidelines are given in an answer form to the often raised questions in developing containerized nursery programs. The guidelines deal with determining seedling needs, choosing the container type and growing facilities, the crop rotations, the location of facilities and size limitations on facilities. Also, a pictorial view is given of an existing facility to illustrate the various components of an operational program.

INTRODUCTION

During my earlier presentation I gave a general overview of the various container nursery programs as they evolved in recent years and also the reasons for containerization. Several other speakers have already discussed the various considerations it takes to begin a containerized seedling production program. For this reason I shall limit my discussion to the questions most often asked when one embarks on the development of an operational container nursery.

HOW DOES ONE DETERMINE SEEDLING NEEDS?

This question needs to be answered first before any planning and designing can begin. The entire program will depend on the amount and type of seedlings needed for a given reforestation program. Such needs are best determined by the land managers and field foresters who are familiar with field conditions, acreages, and reforestation problems.

The seedlings needs must include the amount of seedlings by species, seedling sizes, and their target date for field planting. One must also predict the long term needs and the potential alternatives to these needs.

WHAT TYPE OR TYPES OF CONTAINERS ARE THE BEST FOR THE OPERATION?

As we all know, there are a large variety of containers in use. These come in many different shapes and sizes, and they are made out of a wide range of material. Each container type has some advantages and some disadvantages. Each may suit a given purpose. Therefore, selecting the right and most suitable container is a very important matter.

Container selection shouldn't be based solely on readily available handling equipment at the nursery, or to suit a given planting method. Containers shouldn't be chosen because that is what someone else is using. Such arbitrary selections could lead to the wrong container and many disappointments later.

Some of the most important considerations for container selection should include:

1. It must suit the species and have the potential of producing the desired seedling size.
2. It must interact well with the growing facility. (This will be discussed later in the section on growing facilities)
3. It must support optimum seedling development in height and diameter growth, root structure, side branch development, lignification of the stem, and good bud initiation and formation.
4. It must provide protection for the roots against extreme climatic conditions to produce a hardy seedling in near natural growing conditions.
5. It must be suited for mechanization at the nursery and during field planting.
6. It should be recyclable for repeated use.
7. It should be lightweight, as durable as possible and low in cost.

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[1] Paper presented at Southern Containerized Forest Tree Seedling Conference, Savannah, Georgia, ugust 25-27, 1981.

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Without a doubt these constraints are rather strident. Perhaps none of the containers in use today possess all the listed qualities, but it has been proven that some come closer than others. During my ten years of practical experience in containerization I have had the opportunity to try out most of the container types. This was done under varied conditions from the Northern cold area to the hot tropics. Out of all the container types, the styroblock, or polystyrene container came the closest in meeting the above listed requirements.

WHAT KIND OF GROWING FACILITIES ARE THE BEST?

There is no clear-cut answer to this question. In the past, a whole range of facility types were developed. These facilities range from the open pad to the most sophisticated greenhouses. From practically no environmental controls to the fully controlled growing areas.

Before a decision is made on the type of growing facility, one should consider the following guidelines:

1. The facility type should be well suited to provide the needed environmental controls for growing and for protecting the crop against extreme heat and cold weather, rain, snow, wind, etc.
2. The facility should be as simple as possible for cost savings in building, maintenance, and operation. If possible, all the available natural growing conditions should be utilized to grow a hardy and inexpensive crop. This often depends on how well the crops growing schedule is designed and carried out.
3. The interaction of container and growing facility should be favorable. A practical example may shed some light on this. The shelterhouse developed at Georgia-Pacific interacts well in practically all areas with the styroblock container. The relatively inexpensive shelterhouses equipped with environmental controls, as needed for given locations, provide all the conditions needed for good germination and growing, as well as for crop protection. These shelterhouses may have removable or permanent roof covers. The permanent roof covers are generally equipped for good ventilation with thermostatically controlled fullength roof vents. The sidewalls are either permanently open or, again, fully automated for opening or closing as needed.

Houses with such flexibility have the ability to provide all of the artificial controls needed for growing and protection, which may include heating, lighting, air enrichment, etc., but are quick to open up to take advantage of good ventilation and of the nearly natural growing conditions where this is possible.

The styroblock interacts well with the shelterhouses and because of its good insulating capacity, it protects the roots during hot and cold weather while such weather may be beneficial for hardy seedling growth. This factor is especially important where the stems and buds need to be chilled for deeper dormancy during the hardening phase.

As a general rule, when seedlings are produced in thin-walled containers like paper-pots, Leach cells, book planters, and a whole range of other containers, the seedling roots may then suffer from extreme weather conditions. Such seedling crops may do well in fully controlled greenhouses or in areas where the temperature stays relatively mild. Naturally, in a fully controlled greenhouse, one will end up with an artificial and expensive crop that may have a hard time facing harsh field conditions after outplanting.

HOW MANY CROPS SHOULD BE RAISED PER YEAR?

The answer to this question will greatly depend on local climatic conditions and on tree species. The local climatic conditions because of the environmental controls in the greenhouses may not interfere much with growing the seedlings, but it does determine the field planting conditions.

In areas where field planting is limited to a few months out of the year, regardless of the season, it is perhaps more advisable to stick to a one crop per year rotation. A good example of this is the practice in the Pacific Northwest where crop growing is mostly done during the natural growing season in spring and summer and the trees are planted during the dormant season in winter.

In the areas where trees can be planted from spring through late summer, containerized seedlings come in very handy because they can be planted without being dormant. In a case such as this, even two crops per year can be produced and field planted.

In areas with a moist and warmer climatic condition, like in some of our southern states, it isn't usual to produce 2-5 crops per year with faster developing species.

To illustrate the most extreme possibilities in fast crop rotation I want to sight out experience in the tropics where growing and planting may go on year-round. Here we have produced up to ten crops per year.

Containers are quite suitable for multiple crop rotation but this is often overdone. This may happen in areas where the natural growing conditions and field planting have their limitations. In places like this crops are often grown out of phase with the seasons, thus the crops are raised in expensive growing facilities at high costs. Such crops are often planted out of phase also which results in poor field performance. For better planting scheduling often an entire crop is placed in cold storage for later planting. Such a measure may have an adverse effect on the seedlings and will raise the overall reforestation cost.

HOW ARE GROWING FACILITIES SIZED?

The previously determined seedling needs, container types and sizes, facility types, bench arrangement, and the speed of crop rotation will provide most of the answers to the above question. However, there are also other factors which may play a role in facility sizing and utilization. These come from crop reduction due to seed quality, poor crop quality, and also a variety of other damages. Crop reduction, or fall-down, is difficult to predict ahead of time. But with sowing multiple seed in each cavity with thinning, and with a good rearing and protection program, this can be held to a minimum. With these measures we have averaged well over 90% in usable seedlings during the last ten years at our Cottage Grove facility.

WHERE SHOULD THE GROWING FACILITIES BE LOCATED?

Locating a container nursery is a lot easier than locating a bareroot operation. However, there are still some important factors that need to be considered before a decision is made on a given site. These are:

Climatic Conditions

In spite of the availability of the numerous environmental control mechanisms in containerized nurseries, if possible, one should consider such sites where dependence on control units can be avoided or minimized.

A site with mild climatic conditions that has a lot of sunshine and good air movement naturally would have nearly ideal conditions. Anything close to this should be given preference.

Topographic Conditions and Space Availability

The terrain on the site should be as flat as possible with good drainage. There should be adequate space reserved for support buildings, for storing and handling bulky material such as containers, soil and soil cover, for maneuvering and parking equipment and vehicles. There should always be room left for future expansion even though this may not be in the immediate plan.

Irrigation Water Requirements

There should be an adequate amount of irrigation water available with good water quality. Water quantity and quality can and must be determined before a site is chosen.

The amount of water needed can be calculated. As a general rule, it takes about 10-15 liters of water per square meter of gross growing area for one watering. During the height of the growing season, the seedlings may be watered as many as 2-3 times a week. Naturally, during the early growing stages and during the holding period, a lot less water is required.

The water quality is a very important factor in successful seedling production. Water quality can and must be determined with a complete water test.

Nutrient utilization greatly depends on the pH of the soil medium. The pH of the water, if it is not proper, can easily alter the pH of the soil. Some correction on water pH can be made by using acids or lime. However, even if the corrections are successful, making corrections could become cumbersome in case it has to be done often.

While rearing containerized seedlings, small amounts of nutrients are frequently applied through the irrigation water. Therefore, the mineral content of the water may influence the fertilizer regime. If the nutrient elements in the water are known, corrections for those can be made most of the time and should be made if necessary. However, it could happen that certain elements in the water source are in such an abundant supply that making corrections for them is not feasible. In such a case, the water source should be abandoned.

Labor Source Availability

As a general rule, container nurseries don't require a large year-round labor force. However, there are peak periods during the operation when a sizable work crew is required. Such times include the sowing, thinning, and field shipping periods. Locating a nursery close to a community does eliminate the need of hauling workers in from a distant location or the housing of people near the site.

Power and Fuel Source Availability

Even the simplest or most primitive containerized nurseries have an occasional need for electric power or certain fuel supplies. Occasional power needs can be covered by using in-house generators. Most facilities, however, do require a constant electric power source. In case there is a high risk of losing the crop due to power outages, it is even desirable to have an in-house backup power source.

Besides the need for electric power, other fuels are also needed for heating the greenhouses and for operating equipment. Nearness to a gas line may save cost. However, these types of fuel can be trucked in.

There may be other limiting factors which also need to be considered when a container nursery is located. An important one is the distance to the planting site. This will be covered in the next section.

WHAT IS A GOOD SIZE FOR A CONTAINER NURSERY?

In order to operate a bareroot nursery economically, it has to be relatively large in size, preferably in the several million seedlings per year production range. This is because of the high cost of support buildings and nursery equipment.

Containerized nurseries, on the other hand, can already operate feasibly from a several hundred thousand seedlings per year production capacity. This makes it possible to locate smaller nurseries closer to planting sites that will combat high shipping costs resulting from the bulky nature of containerized seedlings.

Small nurseries might be feasible but not the most economical. Practical experience shows that a nearly ideal size nursery has a capacity of around five million seedlings per year. Such a facility can be run by one experienced nurseryman. By adding one more nurseryman without boosting the equipment and support buildings, the capacity can be increased up to the ten million range.

I could go on and on by stating and answering some of the most often asked questions, but because of time limitations, I would rather show a few slides of an existing facility which shows some of the aspects I have covered so far and perhaps some others would be of interest to the audience.

Slide 1. A distant aerial view of Georgia-Pacific's Cottage Grove Forestry Research Center and container nursery facility.
Slide 2. A close-up view of the plant site itself.
Slide 3. A shelterhouse growing area cluster with ten 50' x 200' shelterhouses, eight 20' x 200' alleys and one 36' x 330' headhouse. Each unit can be operated by itself, but most of the time, when all the houses are filled to capacity, the entire greenhouse cluster is operated as one greenhouse without dividing walls between units.
Slide 4. One 50' x 200' shelterhouse with a permanent roof and equipped with heaters and an irrigation system.
Slide 5. One 20' x 200' alley with a plastic and removable roof cover, with irrigation lines, but without a heater.

Slide 6. The 36' x 330' headhouse. This unit serves as a storage and work area during sowing and later as a growing area also.

Slide 7. Fullength roof vents.
Slide 8. Removable sidewall cover.
Slide 9. Sowing line setup.
Slide 10. Soil loader.
Slide 11. Soil press.
Slide 12. Shutterbox seeding device.
Slide 13. Seed covering device.
Slide 14. Seedling holding benches.
Slide 15. Control house.
Slide 16. Near fully developed seedling crop.
Slide 17. Packaging in containers.
Slide 18. Packaging by extracting seedlings.
Slide 19. Shipping in trucks.
Slide 20. Field planting directly out of the container by using backpacks and dibbles.

CONCLUSION

It is impossible to give a detailed account on guidelines for operational containerized nursery development in a 15-20 minute presentation. However, I am sure that I have covered more useful material in this field in such a short time than there was available to me ten years ago when I was facing the task of developing large scale container nurseries. Since then, I have had the opportunity to go through this process many times under a large variety of conditions and there is no doubt that it was always interesting and challenging.

Today there is a storehouse full of information available on containerization, but unfortunately a lot of it is misused or ignored which consequently makes containers a controversial subject despite all of its many useful applications.

INTEGRATED SYSTEM APPROACH TO CONTAINERIZED SEEDLING PRODUCTION AND AUTOMATED TRANSPLANTING[1]

Barney K. Huang and David B. South[2]

Abstract.--Automated methods for producing air-pruned containerized seedlings under controlled environment were studied using the seedling growing and handling tray system to achieve fully automatic transplanting. Results showed that the integrated system provided superior germination and growth rates and relatively uniform seedlings whose yields were significantly higher than those of conventional plantbed seedlings.

INTRODUCTION

Field transplanting and plantbed operations are among the last few farming practices which have not been mechanized in modern agriculture. The need for a practical means for automating these operations has long been recognized. Little progress has been made in mechanization of seedling propagation and planting techniques, and the laborious traditional methods of using bare-root seedlings by hand or with mechanical setters are still used for planting various trees and farm crops.

Container-grown seedlings offer many advantages in growth, control, and mechanical handling (Huang and Splinter 1968, Huang 1971 and 1973, Morrison and Yoder 1975, Huang et al. 1979). The development of an automatic transplanter has further enhanced integrated system approach to containerized seedling production and transplanting. One-row and two-row multiple-drop automatic transplanters were designed to place containerized seedlings at predetermined intervals in the field thus increasing survival rate, eliminating human error in the operation, increasing transplanting efficiency, and reducing labor requirements.

The water injection opener was found to be a very simple and effective means for opening the ground and providing improved soil moisture, aeration and impedance (Huang and Tayaputch 1973). The device is particularly useful to enhance the multiple-transplanting capability of the transplanter. It allows more than one plant to be transplanted in a row for each indexing cycle which increases the operational speed without loss of efficiency.

Production of 1-0 bare-root hardwood seedlings with large diameter root-collars often can be difficult for the southern nurseryman. A short growing season and irregular germination can contribute to this dilemma. The five-to-seven-month growing season is often limiting for the production of large caliper seedlings. Successful production of sweetgum (Liquidambar styraciflua L.) seems to be especially dependent on sowing as soon as the danger of frost has passed. However, because of delays in fumigation or because of wet or cool weather conditions, seeding of hardwoods is often delayed until late May or early June.

Problems can also arise from sowing seeds with low viability of vigor. Germination of seeds of sycamore (Platanus occidentalis L.) and yellow poplar (Lirodeodron tulipifera L.) often is below 30 percent. Such poor germination results in irregular seedling spacing and variable seedbed density. These factors are very crucial to the production of seedlings with large diameters. For sweetgum, 73 percent of the variation in root collar diameter can be attributed to seedbed density (Webb 1969). The recommended density, to produce large diameter sweetgum seedlings are from 54 to 129 seedlings per square meter, while the seedbed densities of sycamore are 43 to 108 per square meter (Formy-Duval 1973). In general, the lower the seedbed density, the larger the seedling. Seedlings with diameters of one centimeter or more are desired because of increased survival and height growth (Ike 1962, Johnson and McElwee 1967, Webb 1969). To achieve the desired density, the nurseryman often will sow heavily in order to ensure an acceptable stand, and then thin to the desired density when the seedlings are two to three months old. This practice not only increases labor costs but also wastes seed.

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[1] Paper presented at Southern Containerized orest Tree Seedling Conference, Savannah, Georgia, ugust 25-27, 1981.

The use of trade names in this publication oes not imply endorsement by the North Carolina gricultural Research Service of the products amed, nor criticism of similar ones not mentioned.

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Emergence can also be a serious problem, especially for small seeded species such as sweetgum and sycamore. Seed of these species should be firmly pressed into the soil (Vande Linde 1973) but not covered with soil since germination is restricted by soil cover (Bonner 1967). Movement of soil and seed due to wind, heavy rains, or irrigation can result in variable spacing and reduced germination. Even after seedlings have germinated, heavy spring rains have often caused high mortality due to erosion and uprooting of seedlings.

It would be desirable to develop a system that would extend the growing season, provide uniform spacing, and protect seedlings during the critical stage immediately following seed germination. The result of such a system would be the production of more large diameter seedlings per unit area than is generally achieved with the conventional production method. A system involving germinant transplants has been developed for forest trees in Canada (Skeates and Williamson 1979). Black spruce (Picea mariana (Mill.) B.S.P.) seeds were germinated in a greenhouse thereby maximizing seed germination and protecting the germinants from adverse environmental conditions. The germinants were placed into 2.5 cm square peat cubes and grown for one to two months in the greenhouse. In June, the seedlings (rooted in peat cubes) were transplanted manually into trenches across the nursery beds.

This paper presents the automated methods for producing air-pruned intact-root containerized tree seedlings under controlled environment using the seedling growing and handling tray system. Germination, growth and yield studies were carried out for southern hardwoods and pine to illustrate the advantages of automated seedling production system and fully automatic transplanting.

SYSTEM DESCRIPTION

The utilization of containerized seedlings in conjunction with proper handling and transplanting techniques offers definite advantages in reduction of labor for total mechanization, efficient use of plantbed space, and undisturbed seedling roots for healthy growth. However, the use of containerized seedlings involves many economical, physiological, and engineering problems such as container cost, efficient means of seeding, germination, emergence, uniform growth of seedlings, growth media, root development, moisture control, efficient means of removing containers, use of degradable containers, handling of individual seedlings, optimum container shape and size, etc. After extensive research into the above indicated problems and into their possible solution, a seedling growing and handling system was developed (Huang 1973). The device also contemplates the automatic transplanting of th seedlings from the device to achieve the systems engineering of the cultural practices.

The seedling growing and handling system consists of a plural-opening seedling growing and handling tray. Figure 1 illustrates the concept of integrating the tray system with pneumatic automatic transplanter to increase the total operational efficiency. The tray can be made from a thin plastic sheet or metal foil at such a low price that it can be either reused or discarded. The tray consists of many conically shaped or pyramid shaped cells tapered upwards with both ends open. Since the plant roots develop toward the bottom of the pot, a larger bottom not only provides a more desirable shape for root growth but also permits a containerized seedling to drop out easily at the time of transplanting. This pot shape also reduces the exposure of growth media to the atmosphere so that the moisture loss can be reduced.

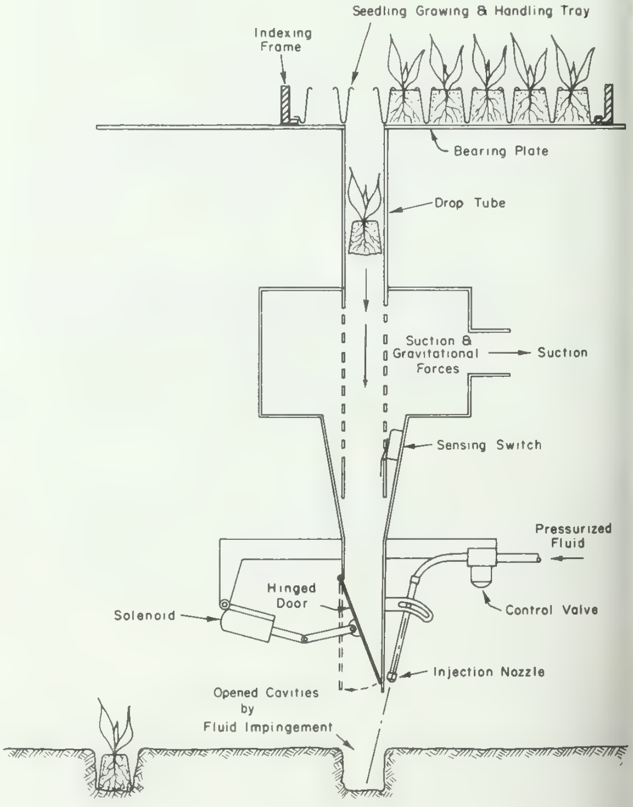


Figure 1.--Operational principle of precision automatic transplanter integrating the tray system with pneumatic transplanting and fluid injection ground opening.

Growing and bulk handling of seedlings for fully automatic transplanting involve (1) filling the plural openings in the growing and handling tray with a growth medium such as soil mix, peat mix, vermiculite mix, growth cubes, etc., (2) planting a seed in the individual opening or placing a preseeded growth medium in each opening, (3) providing an environment conducive to seed germination and plant growth, (4) inserting a bottom plate under the tray at the time of transplanting, and (5) transferring the tray to the indexing frame of the automatic transplanter by pulling out the bottom plate. The tray is progressively shifted by the indexing frame of the transplanter longitudinally and laterally in increments equal to the cell distance. As each containerized seedling is indexed over an opening in the bearing plate, it drops to the ground through a drop tube by gravity and with the aid of suction force. Thus, the containerized seedlings in the tray can be planted directly at the rate of travel of the transplanter and the seedlings are systematically planted at predetermined spaced intervals. The plastic seedling growing and handling trays serve not only as seedling growing and handling containers during plantbed and transferring operations, but also as an indexing grid-cartridge during automatic transplanting. The trays were designed to adapt to the indexing frame of the transplanter. Each tray holds 70 seedlings and the indexing frame carries three trays or 210 seedlings. Figure 1 also illustrates the operational principle of the precision automatic transplanter with a water injection spot opener. The transplanting capacity can be increased by increasing the number of suction-drop tubes. Press wheels are used to support the machine weight, to provide proper coverage of seedling roots with the right amount of soil, and to provide additional compaction to the covering soil. The one-row automatic transplanter used in this study is shown in figure 2.

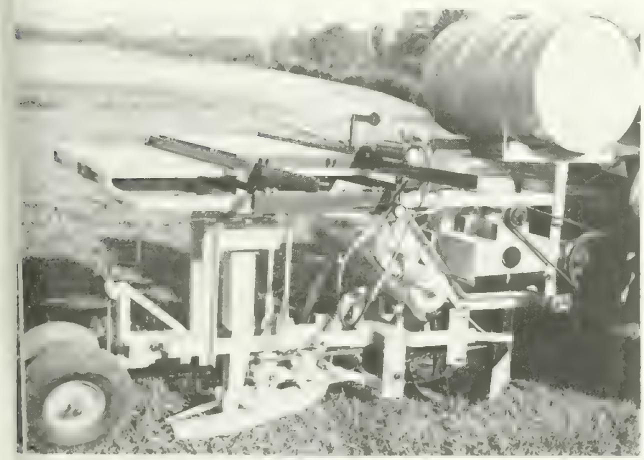
PROCEDURES

Sycamore and sweetgum seeds were collected from northeastern counties of North Carolina. Sweetgum seeds (collected during October, 1973) were stratified for 40 days at 2 degrees C. Sycamore seeds were allowed to mature on the tree before being collected in January, 1974. Germination percentages for sweetgum and sycamore seeds were 91 percent and 30 percent respectively.

Seeds of each species were sown in plastic seedling growing and handling trays (Summit Plastic Corp., Tallmadge, Ohio) in a greenhouse on March 1, 1974. Each tray contained 70 cells, each with 4 x 4 x 5.5 cm dimensions. Cells were filled with a 3:2:1 volume ratio of loamy soil, peat moss and vermiculite. The temperature in the greenhouse was kept above 19°C and the trays were watered during the day with a mist system at 6-minute intervals before germination and a 12-minute intervals after germination. Fertilizer (23-19-17) was applied twice during the two-month period in the greenhouse.

The nursery study was installed at the Federal Paper Board Company nursery at Lumberton, North Carolina. Soil in the test plots was a sandy loam to loamy sand and contained 56 ppm of available P, 28 ppm of exchangeable K, 272 ppm of exchangeable Ca, 39 ppm of exchangeable Mg, and 6 ppm of Mn. The soil contained 1.9 percent organic matter and had a pH of 2.6. The study area was fumigated with 504 kg/ha of methyl bromide (MC-2) on April 5, 1974.

For the broadcast treatment seed were sown by hand at the nursery on April 29, and the beds were mulched with a thin layer of pine straw. On May 6, 7, and 9, 2-month old containerized seedlings from the greenhouse (fig. 3) were



igure 2.--One-row one-drop precison automatic transplanter for containerized seedlings.

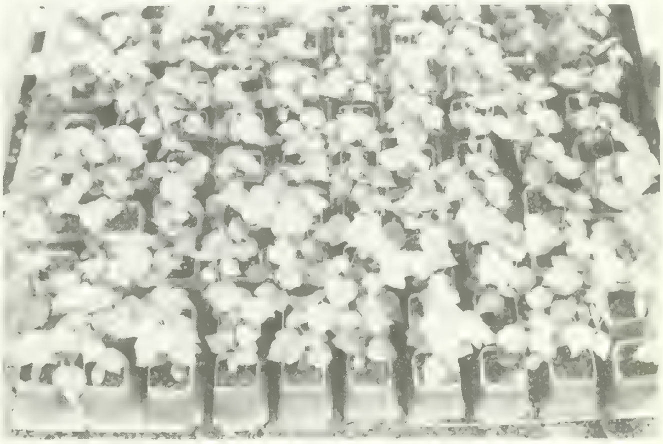


Figure 3.--Seedling growing and handling trays with two-month-old sweetgum seedlings ready for transplanting.

transplanted in trenches 35 cm apart. Seedlings were spaced 2.5 cm apart within each row; this resulted in a density of approximately 129 seedlings per square meter. The transplants were not mulched with pine straw. Plot size for each treatment was 1.2 meters wide by 12.2 meters long. On May 9, heavy rains resulted in considerable erosion of beds in all treatments.

Seedlings were irrigated at the rate of 1.2 cm of water per day until they were approximately 10 cm tall. Fertilizer was applied in 6 applications totaling 390 kg/ha of nitrogen, 118 kg/ha of phosphorus, and 236 kg/ha of potassium. On August 6, the broadcast sweetgum seedlings were thinned to approximately 64 seedlings per square meter.

Heights of seedlings in the plots were measured on June 4, July 9, August 19, October 22, and November 17, 1974, by randomly selecting six codominant seedlings per plot and recording height to the nearest centimeter.

On November 17, root-collar diameters of seedlings from 3 subplots within each plot were recorded. Subsamples were taken at 3 meter intervals, starting and ending 3 meters from the end of the plot. Each subsample was 0.9 meters wide by 1.2 meters long.

The number of man-minutes required for hand-weeding the plots were recorded on June 4, June 20, July 9, and August 6. All variables measured were subjected to analysis of variance.

RESULTS AND DISCUSSION

Seedling production and transplanting tests showed that the seedling growing and handling system achieved the following results.

1. Provided a means of producing a large number of relatively uniform containerized seedlings. The uniformly sized individual root zones allow the seedlings to grow more uniformly throughout the plantbed by restricting root-system expansion of larger plants to slow down the growth since all plants tend to maintain their proper shoot-root ratio. Figure 3 shows the uniformly grown two-month-old containerized sweetgum seedlings ready for transplanting.
2. Provided efficient and minimum use of plantbed space for maximizing uniform seedling production.
3. Eliminated the laborious operation of pulling the seedlings from plantbeds and reduced labor requirements in the seedling handling operations to a minimum.
4. Reduced moisture loss of containerized seedlings in nursery beds by reducing the exposed surface of growth media. This in turn resulted in 2° to 3°C higher temperature in the growth media and root system giving better plant growth compared to conventional plantbeds, flats, and trays.
5. Provided a seedling with efficiently shaped intact root zones. The seedlings could easily be removed from the larger bottom of the container just before being transplanted. The intact root system once transplanted fanned out to insure good ground contact for excellent survival rates and good growth with minimal shock.
6. Adapted to various types of growth media and cuttings of many varieties of plants could be started. The pyramid or cone design of the tray provides good root orientation for future growth and air pruning effect at the open bottom totally eliminated root-tangling or root-bound problem in containerized seedlings for better growth. It was also shown that air-pruned intact-root tree seedlings do not require long root zones as generall believed to provide vigorous growth after transplanting, thus greatly simplify the seedling handling and transplanter design in tree planting. Figure 4 shows the effect of air pruning on pine root formation at various stages of seedling growth.
7. The adaption of seedling growing and handling system to the automatic transplanter was proved to be excellent which resulted in simplification of automatic transplanter and in improvement of the operational efficiency.

Field tests showed that the automatic transplanter performed effective automatic transplantin with a considerably lower labor requirement. Practical application of the water injection opene showed that the opener provided an effective means for opening precision spot cavities in the ground to improve soil moisture, aeration and impedance for better transplanting performance and plant growth. These new developments made it possible to automate the total containerized seedling cultural operations from plantbed preparation, seeding, handling, to the field transplanting.

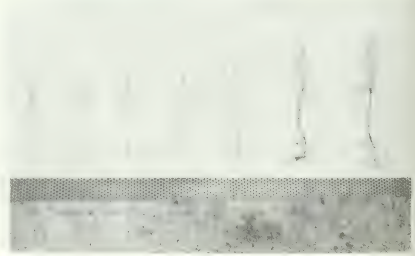


Figure 4.--Effect of air pruning on pine root formation at various stages of growth.

Transplanted seedlings produced more large diameter seedlings, and taller seedlings than the conventional planting as shown in Table 1 and figure 5. There was a three fold increase in large diameter sycamore seedlings and 50 percent more large diameter sweetgum seedlings by using the containerized seedlings. There are two probable reasons explaining why the containerized seedlings were larger than the conventional seedlings. Air-pruned intact-root seedlings generally provide vigorous growth as soon as transplanted and the containerized seedlings were two months older than the conventional seedlings in plots where the seed were broadcast. Height growth curves (figs. 6 and 7) indicate similar growth patterns for both treatments; however, because containerized seedlings were sown earlier in a greenhouse, their growth curves were shifted to the left. In addition, seedlings in conventional plots were probably exposed to greater moisture and nutrient stresses than transplanted seedlings as a result of competition from crabgrass (Digitaria sanguinalis (L.) Scop.). Although the study area was fumigated in the spring with methyl bromide, weeding times on the conventional beds mulched with pine straw exceeded 535 man-hours/ha. The nonfumigated pine straw was apparently contaminated with weed seed. Conversely, beds with containerized seedlings and no mulch required only 42 man-hours/ha of handweeding per hectare (fig. 8). Nonfumigated pine straw mulch has been shown at several nurseries to introduce weeds and increase weeding times (Bland, 1973; South, 1976). Reducing competition from grasses can significantly increase production of hardwood seedlings (South and Gjerstad 1981).

Although this study demonstrated that transplanting containerized seedling into nursery beds extends the growing season, insures uniform spacing, and provides protection of seedlings during the critical germination stage, these benefits were not obtained without additional costs. The additional costs of greenhouses, containers, greenhouse maintenance, automatic transplanter (or hand labor for transplanting) would increase seedling production cost of these species.

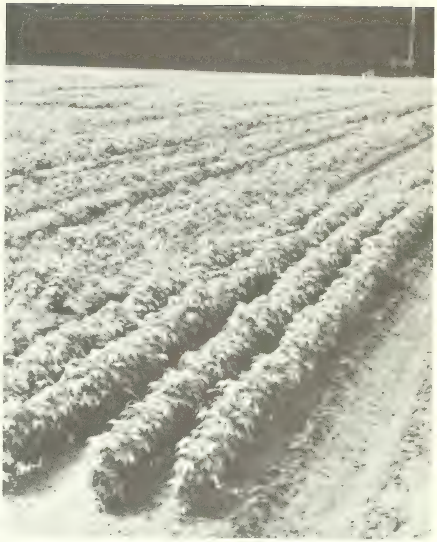


Figure 5.--Growth differences between containerized seedlings in foreground and conventional seedlings in background (July 9, 1974).

Presently, the North Carolina Forest Service sells 1-0 sweetgum seedlings for $60 per thousand and 1-0 sycamore for $85 per thousand. With the limited production in North Carolina in 1980 of 200,000 sweetgum seedlings and 27,000 sycamore (a total of less than one hectare), the total worth of both crops would not exceed $16,000. With this low level of production, any large capital investment would be prohibitive. In order to justify such an expense a higher crop value

Table 1.--Seedling production and height growth from conventional and transplanting methods of propagating sweetgum and sycamore at the Federal Paper Board Nursery in 1974.[a]

Species	Propagation method	Total number of seedlings	Number of plantable seedlings[b]	Height of seedlings on 8/19/74
		Number per square meter		cm
Sweetgum	Conventional plantbed	57	17	38
	Containerized seedlings	86	26	48
Sycamore	Conventional plantbed	28	9	58
	Containerized seedlings	44	28	75

[a] All means of variables within species are significantly different at 0.05 level.

[b] Root-collar diameter for sweetgum plantable seedling was greater than 0.79 cm.
Root-collar diameter for sycamore plantable seedling was greater than 1.1 cm.

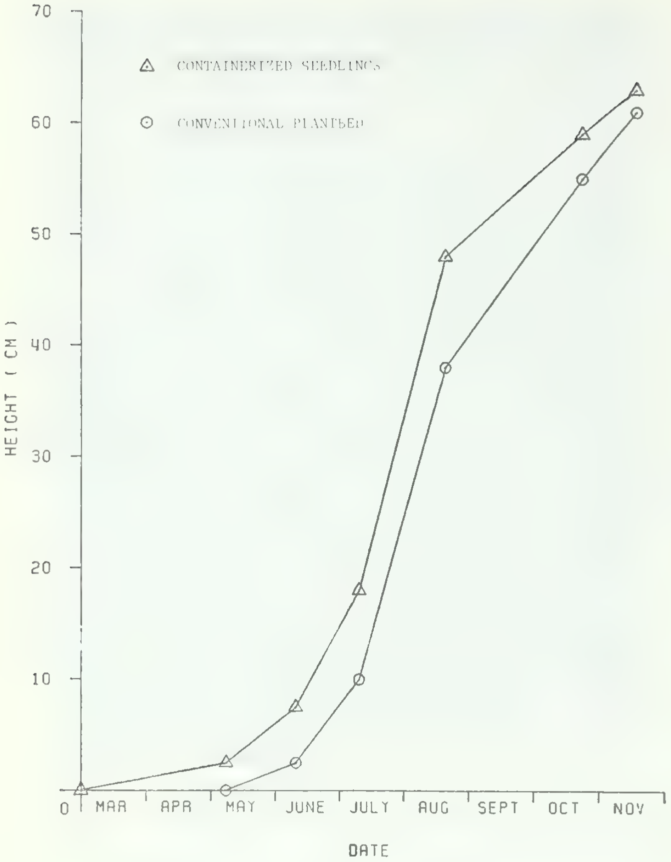


Figure 6.--Average height growth curves for sweetgum seedlings.

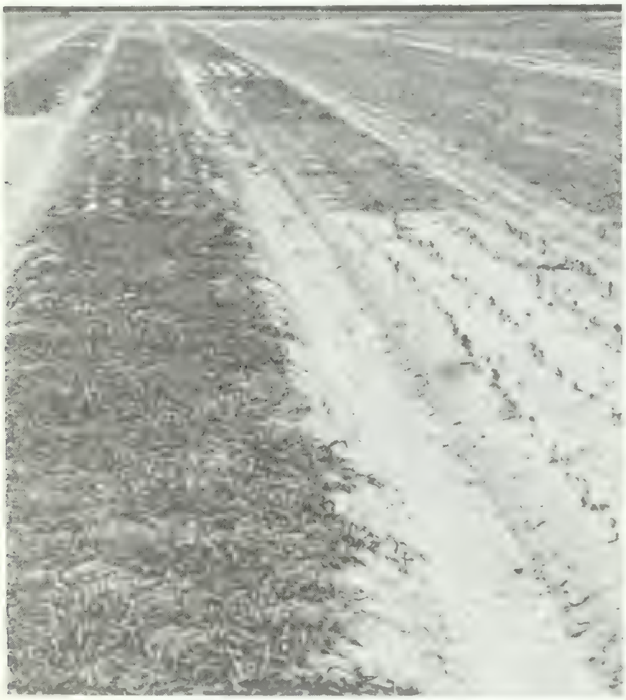


Figure 8.--The pine straw mulched plot (broadcast sown) on the left required the equivalent of 493 more man-hours of weeding per hectare than the nonmulched plot on the right (containerized seedlings).

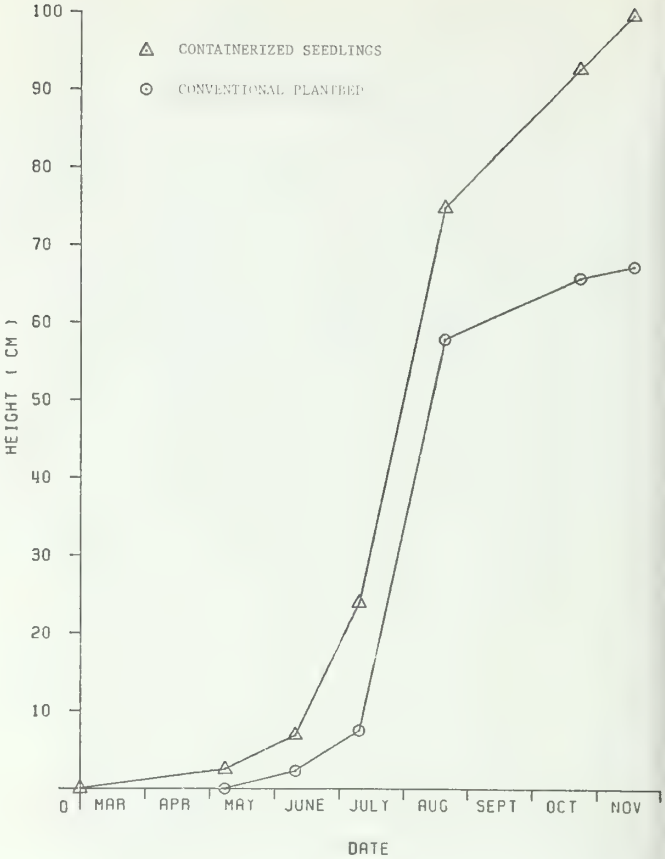


Figure 7.--Average height growth curves for sycamore seedlings.

and/or production of more seedlings would be required. One tree crop in the South for which this system may be applicable is fraser fir (Abies fraseri (Pursh) Poir.). In addition to having limited supplies of seed, this species has low seed germination (3-25%), is slow growing, and has high crop value. One hectare of 3-0 fraser fir seedlings has an approximate value of $400,000 Increasing seed utilization and decreasing the number of years needed to produce a fraser fir transplant would help to offset the additional cost of a germinant transplant system.

This study also demonstrated that the containerized seedling can be automatically transplanted directly from greenhouse into the field especially with water injection spot opener. In this case the above mentioned additional costs of greenhouses, containers and maintenance will be greatly offset by the conventional transplanting costs. Thus, the integrated system approach to containerized seedling production and automatic transplanting would provide a practical means for total tree culture mechanization.

LITERATURE CITED

Bland, W.A.
1973. Study to evaluate the effects and costs of mulching materials in loblolly pine seedbeds. Forestry Note No. 3. North Carolina Forest Service.

Bonner, F.T.
1967. Ideal sowing depth for sweetgum seed. U.S.D.A. Forest Service, Tree Planters' Notes 18:17-18.

Formy-Duval, J.G.
1973. Tree handling, seedlings size and seedling costs. p. 60-62. In Proceedings, Hardwood Short Course, N.C. State-Industry Cooperative Tree Improvement and Hardwood Research Programs. North Carolina State University at Raleigh, N.C.

Huang, B.K., C.G. Bowers, Jr. and P. Oppenheim.
1979. Automated greenhouse seedling production for automatic transplanting. ASAE Paper No. 79-1073.

Huang, B.K.
1973. System engineering of precision automatic transplanting. ASAE Paper No. 73-104.

Huang, B.K. and V. Tayaputch.
1973. Design and analysis of a fluid injection spot and furrow opener. Trans. of ASAE, 16(3):414-419.

Huang, B.K.
1973. Seedling growing and handling device. United States Patent 3,712,252 Jan. 23, 1973. United States Patent Office, Washington, D.C.

Huang, B.K.
1971. Mechanization of cultural operations - plant growth dynamics and automatic transplanting. Annual report of accomplishments in tobacco research in North Carolina, N.C. State University, Raleigh, N.C.

Huang, B.K. and W.E. Splinter.
1968. Development of an automatic transplanter. Trans. of ASAE, 11(2):191-194,197.

Ike, A.F., Jr.
1962. Root collar diameter is a good measure of height growth potential of sycamore seedlings. U.S.D.A. Forest Service. Tree Planters' Notes 59-9-11.

Johnson, J.W. and R.L. McElwee.
1967. Larger sweetgum seedlings are more vigorous two years after planting. U.S.D.A. Forest Service, Tree Planters' Notes 59:1-4.

Morrison, J.E., Jr. and E.E. Yoder.
1975. Uniformity of tobacco seedlings grown in containers. Trans. of ASAE, 18(6):1032-1034.

Skeates, D.A. and V.H.H. Williamson.
1979. Black spruce germinant transplants: the use of pregerminated seed in bare root transplant production. Ont. Min. Natur. Resour., Forest Res. Rep. No. 105. 15 p.

South, D.B.
1976. Pine straw mulch increases weeds in forest tree nurseries. Agricultural Experiment Station of Auburn University. Highlights of Agricultural Research 23(4):15.

South, D.B. and D.H. Gjerstad.
1981. Postemergence control of grasses and selective herbicides in pine and hardwood seedbeds. Agricultural Experiment Station of Auburn University. Auburn University Forest Nursery Cooperative Note. No. 1.

Vande Linde, F.
1973. Hardwood nursery practices, p. 44-52. In Proceedings, Hardwood Short Course. N.C. State-Industry Cooperative Tree Improvement and Hardwood Research Programs, North Carolina State University at Raleigh, N.C.

Webb, C.D.
1969. Uniform seedling density is important in hardwood progeny nurseries, p. 208-216. In Proceedings of the Tenth Southern Conference on Forest Tree Improvement, Houston, Texas.

OPERATIONAL REFORESTATION[1/]

Samuel F. Gingrich[2/]

One of the major forestry problems in the South is the prompt regeneration of pine forests and the establishment of new forests on lands best suited for pine. During the 1950's and early 60's, except for a few years during the soil bank plantings, about one-half million acres of pine were planted annually. By the late 60's and early 70's the annual rate had increased to about three quarters of a million acres. Since 1975 the annual acreage planted has stabilized at about 1.2 million acres. Most of the easy planting, primarily on old fields, was completed by the late 60's when the era of intensive site preparation on cut-over land began. Some of the earlier plantations are now being harvested and although resource statistics may show a slight increase in reforestation acres, the actual forestation of new acres may be decreasing.

Forest resource statistics also show that there are hundreds of thousands of acres in the South, capable of, but not now supporting pine forests. Many of these areas are on difficult planting sites that may have to be man-handled by drainage practices and control of unwanted vegetation before planting. These acres need to be put into production if the South is to meet the projected timber needs of the future. It is a tough assignment and the containerized seedling may play an important role in accomplishing this.

The industrial reforestation programs in the South are impressive but not without serious technical problems that need to be solved. Survival has been low on droughty sites, forest pests such as the tip moth and fusiform rust impose a serious threat in some areas, and site preparation costs are high and going higher.

I prefer to discuss the merits of containerized seedlings rather than compare them with bare rooted seedlings, but the simple fact remains that the operational use of containerized seedlings depends on comparative performance and costs. State forestry agencies and many of the forest industries have made substantial capital investments in nurseries, heavy equipment and seed orchards geared to the production of bare rooted seedlings. One of the facts we have learned in our attempts to have new technology adopted by user groups is that the advantages must be more than a break-even situation because the adoption usually involves a redirection of capital investments and the retraining of personnel.

The literature on the comparative performance of containerized and bare rooted seedlings is inconclusive. Depending on the source of information, differences can be found but in general bonifide experiments have shown no significant differences in terms of survival and early height growth. Most research in containerized planting stock is of recent origin beginning about 10 years ago. Much of the preliminary experimentation and probing, characteristic of new research, has been completed and research efforts should now focus on those technical problems that still remain. Many of these problems deal with operational aspects such as the logistics of the entire production system and improved automation and mechanization. There is some evidence, based on research now in progress, that these problems are being addressed.

There are two areas where containerized seedlings could play an important role in pine regeneration. The first area is those difficult sites that have been avoided in the past. A second possibility is the packaging of a seedling that could perform under conditions involving a minimum of costly site preparation. This will probably mean larger seedlings and a modification of conventional containers, but the cost advantages could be attractive.

The relative merits of containerized planting stock should not only be judged by survival and early growth but also by the eventual stand that will be produced. Small differences in early seedling growth can be quite large when projected into the final stand. For example, if the potential gain from the best containerized growing stock will yield a 5 per cent increase in the number of dominant trees in the final stand, at age 25 the increase in volume would be nearly 6 cords and even more for longer rotations involving the production of sawlogs and peeler logs.

[1/] Presented at Southern Containerized Forest Tree Seedling Conference, Savannah, Georgia, August 25-27, 1981.

[2/] Program Manager, Loblolly Pine Research and Development Program, Southeastern Forest Experiment Station, Forestry Sciences Laboratory, Charleston, South Carolina.

One final item at the very heart of operational reforestation is the need for better quality control from nursery to planting site, and specifically the planting operation. Geneticists have found that in many cases where genetically improved planting stock failed to perform as expected, the cause was related to faulty planting and not the quality of the seedling. There may be a tendency to consider improved planting stock as super seedlings capable of performing growth miracles but the cost of producing containerized seedlings justifies the highest level of quality control. Tree planting is costly--but failures are more costly.

In summary, the operational use of containerized seedlings will require that they be used for more than special cases or experimental use. I believe there is a potential for containerized seedlings to provide an option in the planning of reforestation activities but at this time that potential has not been fully developed. Our speakers this morning are well qualified to discuss operational reforestation including the processing and shipping of containerized seedlings, planting, site preparation and the development and testing of automated tree planting machines.

THE PROCESSING, STORAGE AND SHIPPING OF CONTAINER SEEDLINGS IN THE WESTERN UNITED STATES [1]

Thomas D. Landis and Stephen E. McDonald [2]

Abstract.--Container seedling handling systems in the western United States have evolved to reflect the special requirements of individual nurseries. Seedling containers are transported by hand, pallet or conveyor systems. Seedlings are either processed in the growth container or extracted and boxed, depending on management objectives, degree of seedling dormancy and storage facilities.

INTRODUCTION

Before considering this subject, we should consider the physical differences between shippable bareroot and container tree seedlings. Containerized seedlings are bulkier and heavier than comparably sized bareroot seedlings. Container seedlings are sometimes shipped while not completely dormant and planted throughout the season, whereas bareroot trees are normally shipped fully dormant and only outplanted in the spring or late fall.

Container seedling nurseries use a variety of handling systems. Reforestation objectives or customer needs can generate unique requirements, and handling systems have evolved to meet these demands. Size of the planting program, available transportation, distance to the planting site, on-site storage facilities and type of planting tool all influence the evolution of a container seedling handling system.

Because containerized seedlings are relatively new in reforestation, handling systems are continually being improved. Many container nurseries have radically changed their seedling processing each of the last few years in an effort to increase efficiency and incorporate the newest research.

These processing techniques were developed for western conifer species and may not be applicable to other containerized tree seedlings. Refrigerated storage, in particular, may not be adaptable to southern container nurseries until cold tolerance limits are established for southern species.

CONTAINER HANDLING

Handling containerized seedlings at the nursery is complicated by their bulk and weight. Containers must be handled during sowing, after thinning, when transferred from greenhouse to shadehouse, during packing and at outplanting.

Small nurseries simply hand-carry containers between operations or may use motorized vehicles. One way to minimize handling is to process containers right in the greenhouse which is especially suited to houses with portable benches.

Conveyors are often used to improve container handling. Unpowered roller conveyors are used for short distances and motorized conveyors are becoming common in many nurseries. The Gleason Company (Sumner, Washington) has developed an electrically powered conveyor system for handling tree seedling containers. It is available in portable sections and is also compatible with an automated tray filler.

Pallets are also used to transport container seedlings and are moved with pallet jacks or fork-lift trucks. Pallets serve a double function as growth tables in some nurseries.

/ Presented at Southern Containerized Forest Tree Seedling Conference, Savannah, Georgia, ugust 25-27, 1981.

/ Respectively, Western Nursery Specialist, SDA-Forest Service, Lakewood, Colorado; and orestation and Tree Improvement Specialist, SDA-Forest Service, Washington, D. C.

PROCESSING AND STORING CONTAINER SEEDLINGS

Two processing techniques are commonly used for western container seedlings: 1) storage and shipping in the container in which they were grown, and 2) extraction from the growth container and storage in boxes.

Storage and Shipping in Growth Container

Container nurseries that ship their seedlings to the field in the growth container usually store their stock in a shadehouse until time for outplanting. This storage may consist of a short period in spring or summer or over the winter. The shadehouse offers protection from overheating, intense sunlight and dessication from sun and wind. When overwintering stock in cold climates, seedlings are placed on the ground with sawdust packed around the perimeter to prevent freezing damage to the root system. Winter dessication can occur if hot drying winds or sunlight increase transpiration when the root system is frozen. Adequate shade and complete snowcover can lessen winter drying losses.

The seedlings remain in the shadehouse until a few days before outplanting when they are graded and prepared for shipping. Some nurseries ship their seedlings on tier racks in delivery trucks whereas other facilities package the containers in waxed cardboard boxes which are stacked in the trucks. Unless the delivery trip is short, the trucks are refrigerated to retard seedling transpiration and prevent overheating.

Shipping container seedlings in the growth container is most commonly used when seedlings are not completely dormant. This technique has the advantage of protecting the shape of the root plug which is necessary for dibble planting. Many foresters believe that this technique reduces seedling transplant shock.

Phil Hahn of the Georgia-Pacific Corporation (Eugene, Oregon) has devised the "quarterblock" system of shipping and outplanting container tree seedlings. Specially constructed styroblocks are shipped to the field in boxes, broken into quarter-sections and planted out of an aluminum backpack. When the quarterblocks are returned to the nursery, they are banded together and reused for the next crop.

Several disadvantages are inherent with the "in container" processing method. Shipping and storage volume is high and seedlings can only be graded for shoot characteristics because the root system is never exposed. Unless the containers are disposable, they must be shipped back to the nursery, cleaned, and sterilized before reuse. Returning containers is expensive and some amount of container damage must be expected.

An intermediate method is unique to Leach "Conetainers" because these containers consist of individual plastic "cells" that are removable from the growth rack. This container design permits the growth cells to be removed from the racks and processed individually. The seedlings are graded, bound together with tape or rubber bands and packed into boxes. The advantages of this method are space efficiency as more seedling can be packed into boxes, and individual grading so that no empty cells are shipped. The empty plastic cells must still be returned to the nursery for cleaning and sterilization before reuse.

Seedling Extraction and Box Storage

This processing technique involves complete extraction of the seedling from the growth container at the nursery, and developed because of the high costs inherent in shipping and return containers.

After removal, the seedlings are processed similarly to bareroot seedlings and can be graded for both shoot and root characteristics. The shippable grade trees are accumulated in bundles of 10-25 and the root plugs are wrapped in sheet plastic, saran wrap, or are inserted into plastic bags. Seedling bundles are packed into waxed cardboard boxes, sometimes with a plastic bag liner to retard moisture loss.

The advantages of this processing method include significantly less shipping and storage volume, the ability to grade the root system, no container return problem and the potential for long-term storage.

A disadvantage of this technique is that seedlings must be completely dormant and cold-hardy. This requires careful monitoring of seedling physiology and a cold-hardening period in a shadehouse. Most nurseries using this technique schedule their packing operation during midwinter to insure seedling dormancy. Refrigerat cold storage is required because seedling dormanc must be maintained for several months until outplanting. Planting hoes or shovels rather than dibbles are generally used because the root plug looses its circular form during handling.

Refrigerated Storage

Seedlings shipped in the container are sometimes stored under refrigeration for short time periods, but extracted and boxed seedlings must b stored under refrigeration. Dormant, cold-hardy seedlings are typically stored at temperatures slightly above freezing (33-34°F) for several months. Some nurseries have adopted frozen storage and found that they can store some tree species for up to six months at temperatures of 28°F. By holding temperatures slightly below freezing, the free water in the storage container is changed into ice which almost eliminates stora mold problems. Experience has shown that freezin damage to the stored tree does not occur unless temperatures drop below 25°F.

Storage containers must be sturdy enough to protect the seedlings and support additional weight when stacked. Because high humidity is desirable during storage, waxed cardboard boxes are commonly used and some nurseries use plastic bag liners. These bags are necessary for frozen storage to prevent freezing dessication during long-term storage. Some nurseries even fold over the top of the bag to completely seal the storage box. This practice will eliminate moisture loss but will require constant storage temperatures as temperature fluctuation could stimulate excessive respiration and result in seedling damage.

Refrigerated storage buildings may be located at the nursery, or freezer space can be leased. The performance of storage units should be checked prior to use to insure that desired temperatures can be maintained with minimal fluctuation. Refrigerated vans may be used for storage and can eliminate additional handling between storage and shipping. Many vans are equipped with compressors that run on gasoline or diesel fuel for in-transit cooling or electricity for on-site storage.

Several problems can occur during refrigerated storage of container seedlings. Storage molds, especially Botrytis, are a constant threat to stored seedlings. Botrytis spores are ubiquitous in container nurseries but disease development can be avoided by reducing free moisture on foliage, rouging diseased seedlings during grading and judicious use of fungicides. Freezing injury can be averted by insuring that container seedlings are dormant and cold-hardy before storage. Dessication should not be a problem with plastic wraps and waxed boxes.

Frozen seedling storage introduces some special problems because the trees must be defrosted gradually to prevent injury. Proper unthawing takes 7-10 days at cool temperatures; any attempt to hasten the process will damage the seedlings. Field personnel must be educated in the handling of frozen seedlings so that they can plan for gradual defrosting.

SHIPPING METHODS

As already discussed, the shipping method depends on the seedling and the processing technique. Trees shipped in the growth container will require a rack system in the truck if they are not boxed. Boxed seedlings from refrigerated storage should be shipped in refrigerated vans. Frozen seedlings will have to be protected against rapid temperature increases. Even if trips are short and refrigeration is not available, container seedlings should be shipped in enclosed trucks to minimize overheating and dessication. Refrigerated vans also have the advantage that they may be left at the planting location for on-site storage.

SUMMARY

Containerized seedlings differ from bare-root stock in that they are bulkier and may not be dormant when outplanted.

Container seedling nurseries have developed handling systems which reflect the unique characteristics of their operations.

Seedling containers require frequent handling, and pallet and conveyor systems are commonly used.

Two processing methods are utilized for container seedlings in the west. Nurseries that ship trees in a nondormant condition or do not use refrigerated storage usually leave seedlings in the growth container. The other technique involves removing seedlings from the container, wrapping them in bundles and packing them in cardboard boxes.

Boxed seedlings are held in refrigerated storage, sometimes at temperatures below freezing, until shipment. Seedlings stored in their containers usually remain in a shadehouse until they are shipped in boxes or racks in the delivery trucks.

OPERATIONAL PLANTING OF CONTAINER GROWN SLASH PINE SEEDLINGS ON PROBLEM SITES[1]

Jerry E. Abbott[2]

Slash pine seedlings are grown in Kys-Tree-Start containers for outplanting on problem wet sites between May and October. Approximately 1,250 to 1,500 acres per year are hand planted with container trees by contract crews.

INTRODUCTION

Kirby Forest Industries began planting container trees in 1973 with the initial objectives of:

1) Determining the type of container that is best suited to large scale mechanical planting.
2) Extending the planting season.
3) Obtaining better survival and/or growth than possible with bareroot seedlings.

The containers used in these early plantings were Japanese Paperpots, Agritec Polyloam, BR-8 Gro-Blocks, and a pressed peat block. Also, Kys-Tree-Starts were planted starting in 1975.

Trees were grown in lath houses, moved out to a shade area, then machine outplanted.

The present container operation began in 1978 with construction of a greenhouse for production of container trees for operational planting. The current objective of the container program is to establish plantations on problem wet sites. Approximately 750,000 plantable container trees are grown per year for planting between May and October. This number of trees will plant between 1,250 and 1,500 acres per year, which was determined to be the approximate number of these wet site acres.

SEEDLING PRODUCTION

Slash pine seed is soaked overnight in water prior to sowing. Soaking speeds up germination, which is important during summer months when high temperatures can reduce germination (Barnett 1979). In addition, shade cloth is placed over the outside of the greenhouse roof during the summer.

Kys-Tree-Start containers are seeded by vacuum seeder and hand. The vacuum seeder drops twenty seeds at a time. A larger seeder is not practical with this container because the shape of each block (100 containers) is variable.

The Kys-Tree-Start container is a peat-vermiculite mixture that has fertilizer incorporated in the container. This container is no longer being produced, but we have enough to last through our 1982 season. The main problem associated with this container is that the high nitrogen content of the incorporated fertilizer plus a high water holding capacity tends to produce too much top growth in relation to root development. This tendency can be controlled by careful watering, shorter greenhouse cycles, and top pruning. We tried to persuade the manufacturer to eliminate fertilizer from their process, but we were not successful in doing so.

Seedlings are grown for 4-6 weeks in the greenhouse, then moved to a shade area. Shade cloth is placed over the seedlings for 2 weeks until succulent growth has hardened. The shade cloth is then removed for the remainder of the growing period. Ideally, trees grown in these containers would be outplanted at 12-16 weeks of age. If held longer and rainfall prevents control of growth by withholding water, then additional top pruning may be necessary.

Generally, a new crop is started in the greenhouse every 6-7 weeks. Five crops are required to produce the goal of 750,000 plantable seedlings. Production schedules are modified to meet excessively wet or dry conditions.

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[1] Paper presented at Southern Containerized orest Tree Seedling Conference, Savannah, Georgia, ugust 25-27, 1981.

[2] Tree Improvement & Nursery Operations anager, Kirby Forest Industries, Inc., P. O. Box 77, Silsbee, TX 77656.

PROBLEM WET SITES

The sites that our container program is designed to replant are flat, poorly drained clays and silt loam over clay soils. They typically have standing water during the normal bareroot planting season to the extent that seedling survival is doubtful.

The site preparation methods on these wet sites differes from our regular site preparation only in that the wet sites are bedded. Normal site preparation consists of either KG, windrow, and burn or chop and burn. Chopping is done with tree crushers or drum choppers. Bedding on chopped areas is delayed for 1-1½ years so that the larger material may decompose. On these tighter soils, it is necessary to disc prior to the bedding operation.

PLANTING

A change from machine plant company operated crews to hand plant contractor crews has, for the present, eliminated our need for a container that is machine plantable. All containers are currently hand planted.

Contractors pick up the container trees from the shade area and transport them to the field. Most use racks with plywood shelves to increase the number of seedlings they can haul. Pick-up trucks with campers or vans are used to prevent wind damage and dessication during transport. Throughout the planting operation, the bulkiness of container trees increases the handling cost.

Production rates for container trees average about 1,000 trees planted per man day. As 500-600 trees are planted per acre, approximately 1.8 acres can be planted per man day. The maximum number of the Kys-Tree-Starts that can be carried in a standard planting bag is 200.

Trees are planted with a standard dibble or one designed to the shape of the container. With the peat container it is important that the entire container be planted below the ground. This prevents drying caused by the wicking effect of the peat container.

SUMMARY

The original objectives of our container program have been modified based on changes in our method of operation and experience with container trees. Our program is designed specifically for problem wet sites that are difficult to get established with bareroot seedlings in the normal planting season. Survival of 300 trees per acre after two years is the generally accepted minimum; however, on certain sites that have been replanted several times, somewhat lower stocking would even be acceptable. Generally, plantations are replanted or interplanted if less than 300 trees/acre survive, or where mortality has occurred in spots.

LITERATURE CITED

Barnett, James P.
1979. Germination Temperatures for Container Culture of Southern Pines. South. J. Appl. For. 3:13-14.

METHODS OF SITE PREPARATION AND PLANTING FOR CONTAINERIZED LONGLEAF PINE SEEDLINGS IN NORTH CAROLINA[1]

Donald F. Robbins and H. Grady Harris[2]

Abstract.--Various site preparation and tree planting methods using longleaf pine (*Pinus palustris* Mill.) containerized seedlings were tried on an operational basis in the North Carolina sandhills area. The most effective methods were furrowing or bedding followed by hand tree planting; V-blading with machine planting was successful where conditions were not too severe. Operational use of containerized seedlings of this species was discontinued in 1979 because of consistently poor survival resulting from lack of moisture.

INTRODUCTION

The Forestation Section of the North Carolina Division of Forest Resources began planting longleaf pine (*Pinus palustris* Mill.) containerized seedlings commercially for private forest woodland owners in August, 1977. The purpose of this operational planting of containerized seedlings was to extend the tree planting season and to see if survival problems were less than those that had been encountered with bare root stock.

Due to other commitments in the greenhouse, the month of August had been the earliest date on which containerized longleaf seedlings became available for tree planting. When this planting began the first year, rain was plentiful and adequate survival made the operation fairly successful. Various methods of site preparation and planting were tried; lack of experience was very evident and many problems developed. Planting of longleaf containerized seedlings was continued during the summer and fall months through fiscal year 1979-80 in the sandhills section until weather conditions finally caused such severe survival problems that all such planting was halted.

SITE PREPARATION METHODS

A narrow "Taylor-front mounted plow" V-blade and also homemade, wide V-blades mounted on the front of an International TD-15 and a Case 1150 crawler tractor were used. These V-blades created shallow "scalping" furrows that were between four and eight feet wide and approximately three to four inches deep. In the past, the best survival results had been obtained with longleaf pine bare root stock using these V-blades to create the shallow furrows and following with machine tree planting. Therefore, personnel were anxious to try this method with the containerized seedlings. The V-blade and machine tree planting was done in a one-pass operation.

Fire plow "scalping" to create a narrow shallow furrow was tried. These fire plows were pulled with regular fire control International TD-9 crawler tractors. The "scalping" was done as a separate operation and then followed up with tree planting.

K-G blade and piling was also tried as a site preparation method. In most cases this method was used on sandy areas where the hardwoods were so large that the fire plow or the V-blade method could not be used.

Fire alone was also used in an effort to prepare some areas for planting.

Bedding was also tried at Bladen Lakes State Forest as a site preparation method.

Planting of open fields where no site preparation work was carried out was attempted. It

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1/ Paper presented at Southern Containerized orest Tree Seedling Conference, Savannah, Georgia, ugust 25-27, 1981.

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was feared that competition from the weeds would give serious problems as had been the case in the past, but it was desired to see if the situation would be any better using containerized seedlings.

TREE PLANTING METHODS

Both an International TD-15 and a Case 1150 crawler tractor were used to pull a Reynolds F400 machine tree planter. Both of these tractors did the V-blading and machine tree planting in one operation as was mentioned above. Most of this machine tree planting was done in open fields with a heavy weed cover where competition from the weeds was anticipated. This method was also attempted on some scrub oak areas.

An International Diesel 674 rubber-tire tractor was used to pull a two-seated Whitfield tree planter. A Ford farm tractor was also used to pull a small one-seated machine tree planter. These machine planting methods were mainly used in open fields that required no site preparation. They were also used on areas that had been previously furrowed with the fire plow. These methods were successful as long as the furrow was shallow. If the fire plow furrow was too deep then problems were encountered in getting the machine planter to operate correctly. The rubber-tire tractors could also be used in areas that had been prepared by K-G blade and piling providing that a good site preparation job had been accomplished.

Hand planting was attempted with North Carolina Forest Service homemade planting bars. These bars were made out of 1-1/4 inch square steel stock with a sharp edge that creates a square hole in the ground so that the plug of the containerized seedling can be planted. This method worked real well providing that very loose sand was not encountered and that the ground was not too hard.

Hand planting was also tried using the conventional tree planting bar that is used to plant bare root stock. These bars did not work as well as the homemade bars except on hard clay soil where it was easier to make the planting hole with the conventional bar than it was with the homemade bars.

The Finnish tree planting tool called the "Potapookie" was also used in hand planting. This hand tree planting tool was the only one tried that would work on the very loose sandy soils where the hole would fill up as fast as the conventional and homemade bars were pulled out of the ground. A problem did develop with this tool in some cases when dropping the plugs down into the chute caused damage to some of the seedlings.

PLANTING PROBLEMS

As long as sufficient rain fell both before and after tree planting on deep, sandy, dry sites, reasonable survival of the containerized seedlings was obtained. However, just as soon as rainfall was insufficient after tree planting, or soil moisture fell too low, severe survival problems became apparent. In many cases seedlings would be dead within one to two weeks after tree planting without rain. It was very discouraging to the crews to go out and do the best possible tree planting job that could be accomplished and then have the lack of rain for one to two weeks kill the trees. In many cases, when replanting was necessary and the soil moisture was still low, the replanting failed.

It was found that in machine tree planting with both tree planters used, it was extremely difficult to hold onto the seedlings during planti because there was really nothing to grip. This problem had not been encountered with bare root stock so long as the root collar was at least 1/4 inch thick. However, with the plugs of the containerized seedlings there was not much to hold onto. This fact created problems in getting the seedling into the trench made by the tree planter.

It was discovered that in machine tree planting it was extremely difficult to regulate the proper depth of the seedlings. If the seedlin were planted too shallow in loose sand, the plug would be left high and dry as a result of just one rain washing the sand away from the ridge that was created by the packing wheels. On the other hand, if the seedlings were too deep the needles would be completely covered up by the sand from the packing wheels. In other words, there was less margin for error than had previously been encountered in planting bare root stock by machine. Much better handling and depth control of the seedlings was obtained using planting bars.

Adequate temporary field storage facilities in which to keep the trees after they were picked up from the nursery just prior to tree planting were not available. The nursery had an ideal situation in that the seedlings were stored on benches and an irrigation system was installed so that they could be watered as needed. However, in the field in the areas where tree planting was scheduled such facilities were nonexistent. Therefore, the trays of seedlings were placed on the ground under trees in areas where a hose for watering was available. This watering became a daily problem in that it was difficult to tell whether the seedlings were being watered enough or watered too much. In some cases part of the trees dried out and in other cases they were too wet. Securing someone to water the seedlings on weekends or during off-duty hours became a problem.

A logistical problem was definitely encountered all the way from transporting the seedlings from the nursery to actually planting the seedlings in the ground. A large number of these seedlings could not be carried on a pick-up truck and this problem was not really solved by using a tractor-trailer refrigeration van with racks. Because of poor germination and survival, in many instances the trays would only be half full of seedlings. The logistical problem was more severe once the seedlings arrived at the field where it was discovered that the tree planters could only carry about two trays at a time. A cart made out of bicycle wheels was designed and built. This cart made it possible to carry more seedlings, but it was quite difficult to wheel the cart over many of the prepared areas. And, of course, the machine tree planters could not carry as many containerized seedlings as it could bare root stock. It was finally discovered that one man could best carry four trays of seedlings by locking his fingers and carrying two in each hand. On hand tree planting jobs, one man was required to do nothing but carry seedlings to the people doing the tree planting. And, where large contractors were doing tree planting, one man was needed to do nothing but haul trees on a day-by-day basis from the nursery to the contractor. In open fields areas where the pick-up truck loaded with seedlings could be driven right to the tractor, logistical problems were not as severe as they had been in other cases.

Severe problems with the containerized seedlings were encountered when they were planted during the hot summer months on burned, black soil where a wick effect took place. In some cases as a result of this effect, the trees were dead two days after tree planting. It was discovered very quickly that longleaf pine containerized seedlings cannot be planted on black, burnt soil during the hot summer months even with sufficient rainfall.

Survival problems from weed competition were definitely experienced on those open fields that were planted through the summer months with no prior site preparation work. Even the small scalpers on the machine tree planters did not eliminate nough of the weeds to prevent a survival problem. t was determined that some form of "Scalping" was eeded on these open fields in order to eliminate nough of the weeds to prevent competition from causing a survival problem.

In some cases planting had to be delayed for a period of a month or more after the trees were picked up from the nursery. The seedlings were growing in the trays throughout this period and the longleaf needles became very long; thus transpiration rate increased, requiring more watering. It was, therefore, decided to prune the needles back as is done with bare root stock to reduce the transpiration rate of the seedlings after planting. The effects of this treatment were unknown; the possibility of doing more harm than good was considered. However, no effect on survival was attributed to this treatment.

While the trees were growing in the trays, the root systems grew out of the bottoms of the containers and this additional growth caused some of the plugs to tear up when they were taken out of the trays and book containers for planting. The seedlings were approximately twelve weeks old when picked up from the nursery and this root problem occurred after the fifteenth week.

CONCLUSIONS AND SUMMARY

As a result of weather problems, no containerized longleaf pine seedlings have been planted in the sandhill section since fiscal year 1979-80. North Carolina Division of Forest Resources personnel are not optimistic at this stage of the game about the practice of planting containerized longleaf pine seedlings on adverse dry, sandy sites in the sandhill area, unless planting can be completed during periods when adequate rainfall is assured. In most cases, this condition would occur during the normal tree planting season when bare root stock would be planted and there would be no advantage in using containerized seedlings. If planting is scheduled during the summer months, it would have to be during a wet summer, which cannot be accurately predicted.

It was determined that the best method would be to furrow or bed the area prior to tree planting and allow the soil sufficient time to settle before attempting the planting. Then hand tree planting would be used when there was adequate soil moisture so that the planters would have the best depth control of the seedlings and the best possible survival would be obtained. Use of the narrow V-blade and machine tree planting in one operation would be attempted on those areas where the sand was not too loose during periods of adequate soil moisture when the temperature was also moderate.

It may appear from this presentation that the Division of Forest Resources personnel have a negative attitude towards containerized longleaf pine seedlings. It is not intended to convey this impression; but it should be emphasized that many, many problems are encountered with this species in this type of planting.

FULLY AUTOMATED PLANTING MACHINE

DEVELOPMENT AND TESTING FOR CONTAINER SEEDLING APPLICATIONS

Jerry L. Edwards

The expanded need for improved methods and techniques of mechanical tree planting calls for the design and building of improved tree planters. This article covers the design considerations necessary for the development of semi-automatic and automatic tree planter for bare root and container seedlings.

INTRODUCTION

Approximately one-third of the United States is covered by Forests. This forested land can be placed into two general classifications, commercial timberland and public timberland. The ownership of the commercial timberland is primarily small private land areas. Nearly sixty percent of the small land holdings are east of the Mississippi River. Probably the most alarming statistic is that the private land holdings are presently estimated to be stocked to less than one-half their potential capacity.

One of the primary objectives of resource managers is to optimize timber production. A potential answer to the understocking dilemna is to increase artificial regeneration and more specifically machine planting of those trees. A method contemplated by managers must take into consideration restraints. The restraints on machine planting of artificial regenerations can be grouped in four general areas: (1) social, (2) economic, (3) technical, and 4) environmental.

1. Social restraints are normally of an internal nature to the system and can be the most difficult obstacle to overcome. The degree of acceptance of a new idea or machine by the labor force can ultimately make or break the effort. The greatest test of a social restraint is how the employee's perceived effect upon himself and other employees by his new activity. In the case of a tree planter, the social restraints may be most effected by the willingness of the employee to endure the arduous conditions related with hand planting.

2. Restraints associated with economics are normally very important to small land owners or land managers. It has been predicted that economic restraints will very shortly be dictating the future of Forest management. Improved engineering solutions, which include tree planters (mechanical), can help. However, they will not be accepted until the American economy recognizes that more money must be put into the development in our renewable resources (Cramer 1974). Small landowners find it extremely difficult to justify or, for that matter, obtain loans for any investment in regeneration equipment since their operation is marginal at best.

3. Technical restraints are the type to which engineers are most accustomed. The mechanical aspects, which result mostly from the biological and environmental factors, closely parallel those found in agricultural. The biological aspects of tree planting are virtually unknown. The development of the seedling up until it leaves the nursery has not been investigated sufficiently (Dyson 1968). Most factors relating to the out planting of seedlings as to the seedling's physiological and morphological development are unknown. A review of literature on existing planting practices implies by omission that researchers have presupposed that without biological information, research and development of mechanical tree planters cannot proceed. Fortunately, development has continued. The unfortunate part is that it has been very slow and the route of development circuitous.

4. Environmental restraints, such as moisture, soil nutrients, temperature, and sunlight, are well documented. Failures, in most cases, can be traced to environmental deficiencies or misunderstanding of the basic plant physiological needs.

Mechanical systems for planting trees must deal with the aforementioned factors; however, the things that seem to cause designers as many difficulties as any are planting site conditions. The soil moisture, topography, and residual vegetation (Lawyer 1978) impose severe restraints.

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[1] Paper presented at Southern Containerized Forest Tree Seedling Conference, Savannah, Georgia, August 25-27, 1981.

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The restraints are considered so overwhelming that the land manager is generally reluctant to venture very far into the tree planter development business.

Mechanized planting systems are an attractive alternative to hand planting in most large scale reforestation operations if certain technological problems can be solved. Solutions to many of these problems are not readily apparent and are complicated by the diversity of environmental conditions in which mechanical planting systems must operate. These solutions will require new and innovative designs if mechanized systems are to be widely used.

CLASSIFICATION OF MACHINE CONCEPTS

The first tree planting machine for forestry was based on principles evolved from agricultural machinery. The machines that have developed since then can be broken into the following groups:

Furrow Planters

Continuous Furrow - The device consists of a coulter for making a continuous slit in the soil, following the coulter, a shoe for opening the slit into a furrow for receiving the seedling, and a trailing set of packing feet for firming the soil around the roots.

Many early designers originated, in concept, from transplanting machinces for horticultural nursery, small fruit, or vegetable crops. Even today this is the dominant principle of most tree planting machines used in forestry.

Intermittent Furrow - The planting head maintains only intermittent contact between the planting mechanism and the soil while the machine continues moving at a constant speed. An elongated hole (i.e., intermittent furrow) is made in the soil at each planting spot, this characteristic distinguishes the intermittent from the continuous principle. Soil cutting results from both vertical and horizontal tool motion with intermittent furrow machines.

Although many designs have proven that the intermittent planting principle is a feasible concept, most prototypes have been operationally unreliable or uneconomical when tested in timber land operations.

Spot Planters

Dibble - The name is derived from traditional hand planting techniques where a hole is first made in the soil, the seedling is inserted in the hole, and then the soil is closed around the seedling roots. This principle is distinguished from intermittent and continuous furrow concepts by the more limited contact of the planting head with the soil since all soil cutting or displacement results from vertical tool motion.

At the present time a prototype based on this principle is being tested in Finland that utilizes a sliding gate dibble. The planting head stops to plant while the transport vehicle itself continues forward at a constant speed. The planting stock being used is container seedlings (paper-pots).

Injection - The distinguishing characteristic is that the opening in the soil conforms exactly with the dimensions of the root system being planted and closure of the hole is not required.

There is a prototype based on this principle being tested in Canada. The machine presently being tested is a three-row model. The planting head stops while the transport vehicle continues at a constant speed. The planting stock being used is container type (Walters and St. Jean 1975).

CONCEPTS FOR MECHANICAL TREE PLANTING SYSTEM

In developing new concept and extending old ones, basic guidelines must be set up with respect to the general configuration of the machine. The functional operation of the entire Reforestation Cycle (Lawyer 1978) must be reviewed (see fig. 1) before proceeding to develop the concepts for a machine. The principles of operation of a tree planting machine is on the same order of complexity as typical agricultural or forestry equipment, although some complex controls may be required to ensure the accuracy of certain functions. The machine is considered to be fully automatic and require only one operator, the driver. Plants, either container or bare root stock, in sizes currently used in commercial reforestation. The design takes into consideration that the construction must be substantial enough to withstand operation in the forest environment. Design development does not extend beyond a general description of the working principle of the machine functions.

Planting Stock - The type of planting stock must first be selected (i.e., bareroot, container, etc.) specified as to size, type of container, configuration, maximum physical limits, and special characteristics of the planting stock.

Work Platform - Describes the base on which the planting machine is mounted and may be an integral part of the transport vehicle.

Transport Vehicle - This is the vehicle which provides locomotion to the planting machine.

Ground Speed - Describes the rate of travel of the transport vehicle during the planting operation. "Constant" or "periodic" advance of the vehicle is possible. With periodic advance, the transport vehicle must stop to allow the actual planting operation to take place, while constant does not.

Planting Mechanism - Describes the planting device itself.

Working Principle of the Planting Mechanism - Describes how the planting operation takes place. Two factors are most important in the description--1) the selectivity of the microsite location, and 2) the action of the tool in placing the seedling in the soil. For concepts where other factors are also important, it would be necessary to extend the descriptions accordingly.

Planting Mechanism Motion - Describes the horizontal displacement of the planting mechanism with respect to the work platform over time. With "uniform" motion, the planting tool maintains the same velocity as the transport vehicle at all times. With "variable" motion, the tool velocity varies relative to the transport vehicle during the planting cycle.

Soil-Tool Contact - Describes the interaction of the planting tool with the soil during one planting cycle. With "continuous" contact, the tool is always engaging the soil and with "intermittent" contact, there is a portion of the planting cycle where the tool is not in contact with the soil.

Planting Stock Feed System - Describes the method by which seedlings are moved from the transport racks on the machine to the planting mechanism. Manual machines require a transport operator and at least one other individual to place the plant in its final position in the gound. Semiautomatic machines require a transport operator and at least one other individual to transfer the stock from the transport rack to a mechanism that will then place the seedling in the ground. Fully automatic machines require only one operator, since the machine automatically takes the seedlings from the transport containers and places them into the ground.

Mounting Point of the Planting Mechanism - Describes the location (e.g., front or rear) on the work platform where the planting mechanism is mounted. This position is determined by the location of those components of the mechanism that place the plant in the soil.

Microsite Preparation - Describes the treatment the soil receives prior to planting the seedling. With row scarification, a continual strip is tilled the length of the row, and with spot scarification, only a small area around the plant is tilled.

The concept described here has characteristics f conceptual designs, prototypes, and existing achines. Other factors may be required to escribe concepts not yet proposed or developed. onsideration was given to functional and escriptive aspects, and no attempt was made to nclude size or cost information.

CONCLUSION

Probably the largest deterrent to widespread use of planting machines, both semi-automatic and automatic planters is:

1. The machine's failure to consistently do a satisfactory planting job at a cost competitive with hand planting.

2. The reluctance of land managers, both private and government, to define the long range needs for machine planters and provide the necessary funding to get the development and implementation job done.

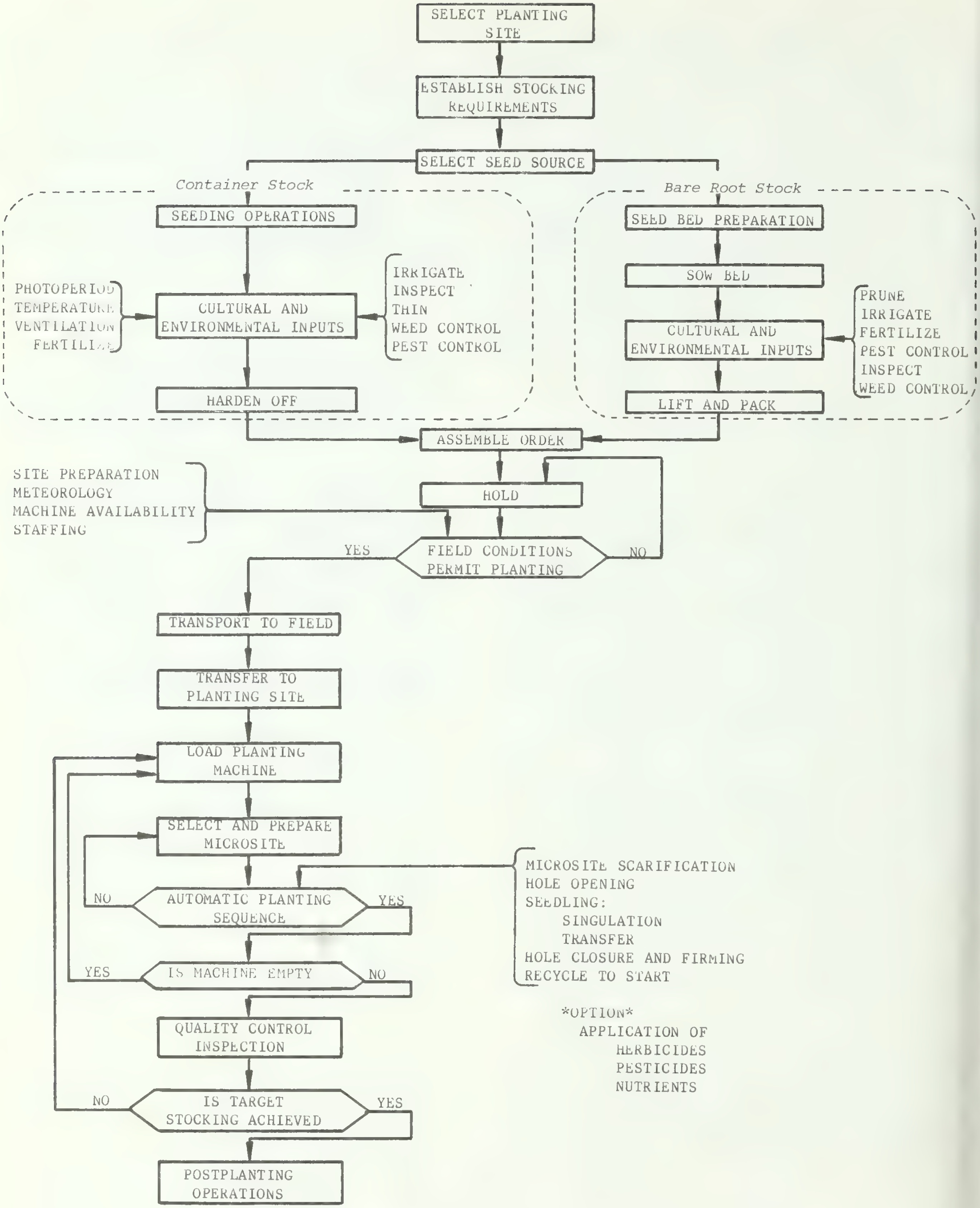
LITERATURE CITED

Cramer, O. P. 1974. Environmental effects of forest residues management in the pacific northwest, a state-of-knowledge compendium. General Technical Report PNW-24, USDA Forest Service, Pacific NW Forest and Range Expt. Sta., Portland, Ore., 517 p.

Dyson, P. J. 1968. Economic restraints dictate future industrial forest management. In ASAE Publ. PROC-368:7-8.

Lawyer, J. N. 1978. Analysis of mechanized systems for planting trees for reforestation. Univ. of Calif., Dept. of Agric. Engr., Davis, 65 p.

Walters, J. and R. St. Jean. 1975. An automated injection-planting machine. ASAE Paper No. 75-1531, 13 p.



Activities in Reforestation Using Mechanical Planters

FIG. 1

CONTAINER SEEDLING SURVIVAL AND GROWTH: PINE AND HARDWOOD IN NORTH CAROLINA[1]

O. C. Goodwin, D. L. Brenneman and W. G. Boyette[2]

Abstract.--After 5 years, loblolly and longleaf pine grown in 2.5 inch^3 containers survived and grew acceptably, with longleaf outperforming 1-0 stock. White pine survival was poorer and growth slower than 2-0 stock. After 1½ to 3½ years, 4 hardwood species grown in 21.5 and 45 inch^3 containers survived and grew well.

INTRODUCTION

The North Carolina Division of Forest Resourcs began experimenting with growing and out plantng container pine and hardwood seedlings in 1972. xtension of the planting season was needed to rovide year-round employment for state forestaion crews and to help meet the need for the annual lanting of 40,000 acres of cutover, private nonndustrial land in North Carolina.

The original project called for the producion and outplanting of tubelings throughout the ear to evaluate techniques used in Ontario, anada (Goodwin 1974). In the fall of 1973, the tudy was expanded to evaluate the Spencer-Lemaire ook planters (now called Rootrainers) and other ontainers. Root-plug containers are preferred ecause roots are not encased in the container en planted and the containers are reusable.

This paper reports on the survival and growth erformance of 3 pine and 4 hardwood species. ased on the performance of these pine tests, the ivision of Forest Resources started commercial oduction of loblolly pine Rootrainers in 1976, ngleaf pine in 1977, and white pine in 1979. rrently, testing is continuing with commercially portant hardwood species.

MATERIALS

Pine

Containers used for southern pine species were the Ontario 3/4-inch diameter, 4-inch long, split-styrene tube; the Spencer-Lamaire Ferdinand 0.8 X 0.9-inch top diameter, 4-inch long Rootrainer; and the half-Styroblock No. 2, 1-inch top diameter, 4.5-inch long container. Each container type has similar dimensions and a volume of 2.5 cubic inches. The 1 X 6-inch Illinois Tool Work (ITW) tube-plug container was used for a white pine test.

Growing media used for pines were fumigated pure peat soil to which was added, per cubic foot, 5 ounces of dolomitic lime and 1 ounce of 10-10-10 pulverized fertilizer with trace elements; and a 1:1 mixture of sphagnum peat-vermiculite to which was added, per cubic foot, 3 ounces of dolomitic lime and 2 ounces of pulverized 10-10-10 fertilizer with trace elements. Two ounces of weathered shredded pine straw were added per cubic foot of growing media as a possible source of ectomycorrhizae inoculum.

Unimproved seed collected from North Carolina sources were used in all tests.

Hardwoods

Containers used for hardwoods were the Ontario 1 X 8-inch split-styrene tube and the Spencer-Lamaire Tinus and Super-45 Rootrainers. These containers are, respectively, 8, 7.25, and 9 inches long and 6.3, 21.5 and 45 cubic inches in volume.

Growing media used for the 1977 tests were a 1:1 peat-vermiculite mix to which 2 ounces of dolomitic lime per cubic foot was added to adjust the pH to 5.5. For the 1979 tests, a 3:1 peat-vermiculite mix was used to which 4 ounces of dolomitic lime per cubic foot was added. Peters 20-19-18 and 9-45-15 water soluble fertilizers were applied with irrigations.

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[1] Paper presented at Southern Containerized rest Tree Seedling Conference, Savannah, George, gust 25-27, 1981.

[2] Authors are Senior Project Forester, Pine lviculture, N. C. Division of Forest Resources, leigh, N. C.; Senior Project Forester and oject Forester Hardwood Silviculture, respective-, N. C. Division of Forest Resources, Morganton, C.

The growing nedium used for all subsequent testing was a 1:1 peat-vermiculite mix to which was added, per cubic foot, 5.0 ounces of dolomitic lime (to adjust pH to 6.5), 7.5 ounces of Osmocote 18-6-12, 2.5 ounces of triple super-phosphate, and 4 grams of fritted trace elements. Fertilizer was added to the media because leaf interception made spray applications unsatisfactory.

For mycorrhizal treatment, 1 part of forest soil, naturally infected by Glomus mossae, was mixed with 8 parts of growing medium for the black walnut, white ash and yellow poplar tests.

For mycorrhizal treatment of northern red oak growing medium, Pissolithus tinctorius inoculum, prepared by Abbotts Laboratories, was mixed at a ratio of 1:10 by volume.

All seeds were collected near where the tests were installed.

SEEDLING PRODUCTION

Pines

All pine container seedlings were grown in the experimental greenhouse at Clayton, North Carolina. Species tested were loblolly (Pinus taeda L.), longleaf (P. palustris L.), and eastern white pine (Pinus strobus L.)(Table 1).

Table.--Container pine production regimes

Species	Grown in greenhouse	Hardened outdoors
	------------weeks------------	
Loblolly pine	5 to 12	4 to 6
Longleaf pine	3 to 9	4 to 6
White pine	5 to 16	5 to 6

Seedlings were germinated and grown in the greenhouse until they reached a desired height. They were then moved outdoors to complete their growth and to lignify their stems prior to planting.

Hardwoods

All hardwood container seedlings were grown in the experimental greenhouse at Clayton. Species tested were black walnut (Juglans nigra L.), white ash (Fraxinus americana L.), sweetgum (Liquidambar styraciflua L.), and yellow poplar (Liridendron tulipifera L.) (Table 2).

Table 2.--Container hardwood production regimes

Species	Grown in greenhouse	Grown outdoors
	------ weeks ------	
Black Walnut	9	7
White Ash	12-15	3
Yellow-Poplar	11-16	4
Northern Red Oak	7	5

No special measures were taken to harden the seedlings. They were moved outdoors in June where they were held until the lower stems became woody.

For all species except northern red oak, also water-soluble fertilizers, 20-19-18 and 9-45-15, were applied weekly in combination at the rate of 150 ppm N and 22 ppm P while the seedlings were in the greenhouse. With each fertilizer application, the seedlings were irrigated to the drip point. Water-soluble nutrients were not applied to the 1978 northern red oak because fertilizer had been mixed with the growing medium.

TESTS LAYOUT

Pines

Pine tests consisted of 0.5 to 2 acre plots located on recently cutover areas which had been site prepared.

Ten loblolly tests were planted; seedlings were planted in the months of April, July, August and September. Nine longleaf pine tests were planted; seedlings were planted in the months of March, July, August, September, October, and November. All 1-0 stock was planted during the spring following the planting of container seedling

Loblolly seedlings were dibble planted at a spacing of 7 X 8 or 7 X 10 feet, longleaf at 5 X 10 feet, and white pine at 7 X 9 feet. Root plugs were removed from the containers and planted approximately ½ inch deeper than the root collar. The tops of the plugs were covered with soil to prevent drying by a wicking-effect.

Care was taken to keep the growing medium moist at all times prior to planting. Generally, soils were moist or rainfall occurred shortly after planting.

Mean survival and growth were determined from measurements of all living pine seedlings in each systematically selected fifth row. Samples of an equal number of 1-0 seedlings were measured in rows adjacent to the container seedlings.

Hardwoods

Hardwood tests were replicated 2 to 4 times in randomized plots of 20 trees with buffers between plots. Tests were planted in July, August, and September. All sites were thoroughly prepared before planting.

Except for northern red oak planted at 7 X 7 feet, seedlings were planted at a spacing of 9 X 9 or 10 X 10 feet. Shovels were used to prepare the planting holes. The same precautions were taken, as with the pine, to keep the media moist at all times and to cover the tops of the plugs at planting to prevent drying by a wicking-effect. Moist soil conditions were a requisite for planting.

Survival and height data were recorded for all trees in each plot.

WEED AND BRUSH CONTROL

Release of pine seedlings was not necessary due to the quality of the site preparation jobs. Because the hardwoods were planted on more fertile sites, they required periodic weeding thoroughout the growing season. Weeding will continue until the seedlings have outgrown the weed competition.

RESULTS

Survival and growth of the various container seedling tests are reported for 5 full growing seasons for the pine and for either 1½ or 3½ growing seasons for hardwoods. The ½ growing eason refers to the remaining portion of the eason following planting in the summer.

Pines

oblolly Pine

Survival.--Mean survival of 10 tests after growing seasons was about the same for tubeings and rootrainers, 73% and 75%, respectively, ut was considerably lower than for 1-0 seedlings 87%). The best survival of tubelings was 90% or an April planting. (Table 3) (Goodwin 1979).

Diameter Growth.--The mean dbh of the coastal 1-0 seedlings was slightly but consistently larger than the container seedlings (2.6 vs. 2.4 inches). The best dbh growth of container seedlings was 3.0 inches. The mean dbh for Piedmont 1-0 seedlings and tubelings was smaller than that for Coastal Plain tests (Table 4).

Height Growth.--Mean total height growth of the Coastal Plain 1-0 seedlings was 1.7 to 2.9 feet greater than that of the container seedlings. The one exception was the July 25 planted root plugs which averaged 15.8 feet compared to 15.3 feet for the 1-0 seedlings.

Of the container seedling heights, the July planted tubelings had the best height growth being much better than the spring and fall planted tubelings (Table 5).

Longleaf Pine

Survival.--Good survival of the container seedlings was obtained for each of the 6 months that planting was done (Goodwin 1980). Survival was considerably higher for container seedlings than for 1-0 nursery stock. Mean survival was 77% for the container seedlings and 64% for the nursery stock. The highest survival was 93% for an August tubeling planting (Table 6).

Diameter Growth.--Measurements of dbh were not taken because of stiff needles growing on the longleaf trunk at this early age.

Height Growth.--In the tests with direct comparison, the container longleaf seedlings were as tall or taller than the 1-0 seedlings. Mean heights were 6.8 feet for root plugs, 4.7 feet for tubelings, and 3.1 feet for 1-0 nursery stock. Best height growth was for the July and August plantings. Some of these trees were 14 feet tall.

The container seedlings grew more uniform in height than the 1-0 seedlings and they grew out of the grass stage sooner than the 1-0 seedlings.

White Pine

Survival.--Four tubeling tests were installed in 1973 with the planting of 11 weeks old seedlings. Frost-heaving decimated 3 of the tests in the first winter following August, October, and November planting dates. The fourth test, a September planting, had only 44% survival and would have been lower except that the slightly heaved tubelings were pushed back into the soil.

In June, 1976, a test was installed with the planting of 22-week old seedlings grown in ITW and Ferdinand Rootrainer containers. Nursery 2-0 stock was planted the following spring on the remainder of a 7 year old white pine plantation destroyed by wildfire. (Goodwin 1978)

Table 3.--Mean survival of 10 loblolly pine container and 1-0 nursery stock tests in North Carolina after 5 full growing seasons

Date planted	Age (weeks)	Site preparation method	Survival (Percent) Tubelings	Root Plugs	1-0 Stock[1]
		Coastal Plain Sites			
April 30	19	KG and pile	90	-	92
July 25	13	Disk and bed	63	-	81
July 25	13	Disk and bed	81	-	81
July 25	13	Disk and bed	67	-	80
August 15	9	Chop and bed	78	-	85
August 15	9	Chop and bed	-	85	85
September 27	9	Chop and bed	60	-	94
September 28	9	Chop and bed	-	63	94
Mean survival			73	75	85
		Piedmont Sites			
April 17	18	Disk	83	-	89
July 6	10	Disk	65	-	89
Mean survival			74	-	89

Table 4.--Mean dbh of 10 loblolly pine container and 1-0 nursery seedling tests in North Carolina after 5 full growing seasons

Date planted	Age (weeks)	Site preparation method	Mean dbh (inches) Tubelings	Root Plugs	1-0 Stock[1]
		Coastal Plain Sites			
April 30	19	KG and pile	1.7	-	2.2
July 25	13	Disk and bed	3.0	-	2.9
July 25	13	Disk and bed	3.0	-	2.9
July 25	13	Disk and bed	2.6	-	3.0
August 15	9	Chop and bed	2.2	-	2.3
August 15	9	Chop and bed		2.2	2.3
September 27	9	Chop and bed	1.8	-	2.4
September 28	9	Chop and bed		1.7	2.4
Mean dbh			2.4	2.0	2.6
		Piedmont Sites			
April 17	18	Disk	1.7	-	2.2
July 6	10	Disk	1.6	-	2.2
Mean dbh			1.6	-	2.2

[1] Planted in February or March following planting of container seedlings.

Table 5.--Mean height of 10 loblolly pine container and 1-0 nursery seedlings tests in North Carolina after 5 full growing seasons

Date planted	(weeks)	Site preparation method	Mean height (feet) Tubelings	Root Plugs	1-0 Stock[1]
		Coastal Plain Sites			
April 30	19	KG and pile	10.6	-	13.2
July 25	13	Disk and bed	15.1	-	15.3
July 25	13	Disk and bed	15.8	-	15.3
July 25	13	Disk and bed	13.3	-	15.9
August 15	9	Chop and bed	11.9	-	13.9
August 15	9	Chop and bed	-	12.7	13.9
September 27	9	Chop and bed	10.3	-	13.5
September 28	9	Chop and bed	-	10.6	13.5
Mean height			12.8	11.6	14.5
		Piedmont Sites			
April 17	18	Disk	9.8	-	12.2
July 6	10	Disk	11.8	-	12.2
Mean height			10.8	-	12.2

1/ Planted in February or March following planting of container seedlings.

Table 6.--Mean survival and height of 9 longleaf pine container and 4 1-0 seedlings tests on sandhill sites after 5 growing seasons

			Survival (percent)			Mean height (feet)		
Date planted	Age (weeks)	Site preparation method	Tubelings	Root Plugs	1-0 Stock	Tubelings	Root Plugs	1-0 Stock[1]
March 27	15	Chop & furrow	85	-	-	2.0	-	-
July 25	7	Disk & bed	84	-	-	8.0	-	-
Aug. 6	9	Disk & furrow	93	93	69	8.4	8.3	3.7
Aug. 15	9	Disk & bed	67	78	-	5.9	6.0	-
Aug. 25	8	Disk & furrow	87	-	-	3.0	-	-
Sept. 26	8	Disk & furrow	78	-	69	1.2	-	1.7
Sept. 28	9	Disk & bed	52	51	-	6.2	6.4	-
Oct. 17	11	Disk & furrow	80	83	67	6.4	6.7	5.2
Nov. 18	11	Chop & bed	79	-	50	1.6	-	1.6
Means			78	76	64	4.7	6.8	3.1

1/ Planted in February or March following planting of container seedlings.

urvival after 4 growing seasons was 63% for ITW eedlings and 41% for Rootrainer seedlings. Surival of 2-0 stock was estimated to be 80%. High ortality of the container seedlings is attributed o the abnormally dry summer after seedlings were lanted.

Height Growth.--After 5 growing seasons, the urviving 1973 September planted tubelings averged 2.1 feet compared to 5.3 feet for the 2-0 tock.

After 4 growing seasons, the ITW seedlings ere taller than the 2-0 and Rootrainer seedlings. hey averaged 2.2 feet compared to 1.9 feet for e 2-0 seedlings and 1.8 feet for the Rootrainer eedlings. Dense hardwood sprout competetion hindered growth of the seedlings.

Hardwoods

The 1 X 8 inch plastic tubes proved to be unsatisfactory. Although some good seedlings were produced, planting failures resulted from root constriction by the tubes.

Black Walnut, White Ash, Yellow-Poplar

Two tests were installed for black walnut, yellow-poplar, and white ash. Nursery stock was unavailable for the first test which is 3½ years old. Nursery 1-0 stock was planted in the second test which is 1½ years old. Results of both tests are reported.

Survival.--Mean survival for the 1977 test is shown in Table 7 (Boyette, Brenneman, Goodwin 1981).

Table 7.--Percent survival and mean heights of 1977 tests after 3½ growing seasons by species and treatment

Treatments	Yellow-Poplar Survival (Percent)	Yellow-Poplar Height (feet)	Black Walnut Survival (Percent)	Black Walnut Height (feet)	White Ash Survival (Percent)	White Ash Height (feet)
45-in.^{3} Container	60	13.6	83	6.6	83	10.1
45-in.^{3} Container + Mycorrhizae	68	12.8	83	5.9	91	10.1
21.5-in.^{3} Container	44	10.7	90	7.4	77	9.2
21.5-in.^{3} Container + Mycorrhizae	58	12.6	97	6.9	74	9.0

Survival ranged from 44% to 68% for yellow-poplar. High mortality of the yellow-poplar resulted from damage to the tender seedlings when they were hand-released from morning-glory vines. The more woody black walnut seedlings were not damaged.

Survival was good to excellent for both the black walnut (83% to 97%) and white ash (74% to 91%).

Yellow-poplar and white ash grown in the larger container survived best, but black walnut grown in the smaller container survived best.

Mean survival after 1½ growing seasons for the 1979 tests was good with the single exception of black walnut container stock (9%-20%)(Table 8).

Table 8.--Percent survival and mean heights of 1979 tests after 1½ growing seasons by species and treatment

Treatment 1/	Yellow-Poplar Survival (Percent)	Yellow-Poplar Height (feet)	Black Walnut Survival (Percent)	Black Walnut Height (feet)	White Ash Survival (Percent)	White Ash Height (feet)
45-inch^3 Container	91	2.1	9	0.0	100	1.9
21.5-inch^3 Container	91	1.5	20	1.0	87	1.8
1-0 Nursery Stock	100	2.1	88	1.7	98	2.0

1/ No appreciative infection of roots was achieved for mycorrhizal treatments, therefore, data is combined for containers.

Failure to properly keep the black walnut medium moist at all times on the outdoor benches, resulted in drying of the medium to a point where it could not absorb water when irrigated. This condition was caught too late to rectify, and it is believed to be the cause of the high mortality occurring shortly after planting.

Survival of the 1979 yellow-poplar was much better because they were not damaged during the weeding operation. Survival for white ash ranged from 87% to 100%.

Height Growth.--Yellow-poplar and white ash grown in the 45 inch^3 containers were slightly taller after 3½ growing seasons than those grown in the 21.5 inch^3 containers.

Height growth results of the black walnut seedlings were confounded during the second growing season from grazing by a stray cow.

Because the control seedlings had some mycorrhizal infection, despite fumigation precautions, the mycorrhizae results were also confounded.

For the 1979 test, height growth was slightly better for white ash and yellow-poplar grown in the 45 inch^3 container. The 1-0 seedlings were approximately one inch taller than container stock after their first growing season.

Northern Red Oak

Mixing laboratory fermentor-produced inoculum of Pissolithus tinctorius at 1:1 ratio resulted in 5% to 20% of the northern red oak container seedling roots becoming infected with 2 kinds of ectomycorrhizae. One species was identified as Cenoccum grandiforme and the other appeared to be Pissolithus but was not positively identified as such.

Survival.--Survival was fair to excellent after the first growing season for all treatments (79% to 95%) (Table 9).

Table 9.--Percent survival and mean heights of northern red oak container stock after 1½ growing seasons

Treatments	Survival (Percent)	Height (Feet)
45-inch^3 Container	96	1.6
45-inch^3 Container + Mycorrhizae	79	1.6
21.5-inch^3 Container	89	1.5
21.5-inch^3 Container + Mycorrhizae	87	1.7

Height Growth.--After 1½ growing seasons, there was no appreciable difference in heights of oak seedlings of various treatments. They ranged from 1.5 to 1.7 feet tall.

CONCLUSIONS

Tests conducted by the North Carolina Divi- ion of Forest Resources, beginning in 1972 and ontinuing to the present, have demonstrated that outhern species of pine and hardwood container eedlings can be successfully outplanted on pro- erly prepared areas in North Carolina.

After 5 full growing seasons, survival and rowth of loblolly container seedlings was not uite as good as 1-0 seedlings; however, longleaf ontainer seedlings survived better and outgrew -0 seedlings on sandhill sites.

After 4 growing seasons, white pine rootrainers id not survive as well but were equal to or better han 2-0 seedlings in height. White pine tubelings ailed because of frost-heaving and did not grow s well as plug seedlings.

After 1½ to 3½ growing seasons, black walnut, hite ash, yellow-poplar, and northern red oak rvived and grew well where good weed control was intained.

Containers having volumes of approximately 5 cubic inches were satisfactory for pines. Containers of 45 cubic inch volume produced slightly better resulcs for hardwoods than 21-inch^3 containers although the smaller containers were satisfactory.

Container seedlings can be used advantageously in a forestation program to extend the normal planting season to early fall, to reinforce or replant failures the same season, to plant low areas too wet to plant during the normal season, and to provide longer working periods for planting labor. Container seedlings for the species tested do not show potential for replacing nursery stock for the bulk of forest tree planting in North Carolina.

LITERATURE CITED

Goodwin, O. C.
1974 Interim report on tubeling study, Forestry Note No. 8, N. C. Div. of Forest Resources, 36 p.

Goodwin, O. C.
1979 Five-year comparison of loblolly pine containerized and 1-0 nursery seedlings planting in North Carolina. Forestry Note No. 38, N. C. Div. Forest Resources

Goodwin, O. C.
1980 Containerized longleaf pine seedlings survive better and grew faster on sandhill sites after 5 growing seasons. Forestry Note No. 42, N. C. Div. Forest Resources, 5 p.

Goodwin, O. C.
1978 Performance of white pine containerized seedlings in N. C. Paper presented at USFS Symposium on interior pines of South, Knoxville, Tenn.

Boyette, W. G., Brenneman, D. L., and Goodwin, O. C.
1981 Survival and growth of white ash, yellow-poplar, and black walnut containter seedlings after 3½ growing seasons. Forestry Note No. 50, N. C. Div. Forest Resources

MYCORRHIZAL INOCULATION IMPROVES PERFORMANCE OF CONTAINER-GROWN PINES PLANTED ON ADVERSE SITES[1]

John L. Ruehle[2]

Abstract.--Container-grown pine seedlings with well developed *Pisolithus tinctorius* ectomycorrhizae can be successfully used in forestation of adverse sites created by surface mining. Results of some current research on coal spoils and borrow pits illustrate the benefits of mycorrhizal technology for forestation of adverse sites.

INTRODUCTION

Conventional artificial or natural techniques often fail to reforest adverse sites created by surface mining and poor soil management. When forestation is the option selected for reclamation, survival of bare-root seedlings planted after routine site preparation is often poor. Efforts to ameliorate adverse sites will be most successful when both physical and biological methods are integrated. Subsoiling to fracture indurate soil surface layers, addition of organic matter to restore necessary physical, chemical and biological factors, and a combination of grass cover and forest tree seedlings colonized with beneficial mycorrhizal symbionts ecologically adapted to adverse sites should be considered in an integrated plan for forestation of adverse sites.

Bare-root pine seedlings have often been used for reclamation of surface mines. Adverse extremes in pH, low nutrient status, high concentrations of toxic substances, elevated surface temperatures, and droughtiness have contributed to poor performance by this type of growing stock. Often mycorrhizal fungi on this type of planting stock are adapted to nursery conditions, but are not ecologically adapted to the adverse site (Marx 1977). Performance of bare-root pine seedlings on such sites was greatly improved when they were "tailored" with *Pisolithus tinctorius* (Pt), a symbiont well adapted to many adverse sites (Marx and Artman 1979, Walker and others 1980).

In certain areas, rainfall patterns are better for planting in summer and fall than in winter or early spring, the best time for planting of dormant bare-root stock. Consequently when off-season planting is desirable, containerized pine seedlings should be considered for reforestation of difficult sites (Barnett 1980). This type of planting stock can be planted in summer when environmental conditions favor seedling establishment. Inoculating container-grown pines with Pt prior to planting also aids survival and early growth on certain adverse sites (Ruehle 1980, Berry[3]).

MINING SPOILS

In a comprehensive review of the significance of mycorrhizae to forestation of surface-mined lands, Marx (1980) stated that pine seedlings naturally colonized with Pt survive and grow well on mining spoils. Berry[3] confirmed the value of Pt in a recent study on two strip-mined coal spoils in the South. Pine lines comprised of loblolly, pitch, and loblolly x pitch pine hybrids were grown in containers with Pt. During the 16-week growing period in the greenhouse a comparison set of control seedlings became naturally colonized with *Thelephora terrestris* (Tt) ectomycorrhizae. Seedlings were then outplanted on acid coal spoils in Tennessee and Alabama in mid-July. Treatment plots of 16 trees of each line were randomly arranged in 5 blocks at each site. After two and one-half growing seasons the results were striking (Table 1). On both sites seedlings with Pt ectomycorrhizae had greater survival, height, and root-collar diameter than naturally inoculated seedlings. Volume indexes on plots with Pt ectomycorrhizae were 200 percent greater in Tennessee and 380 percent greater in Alabama than indexes of control seedlings with Tt ectomycorrhizae.

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[1] Paper presented at Southern Containerized Forest Tree Seedling Conference, Savannah, Georgia, August 25-27, 1981.

[2] Plant Pathologist, Institute for Mycorrhizal Research and Development, USDA Forest Service, Forestry Sciences Laboratory, Carlton Street, Athens, Georgia 30602.

[3] Berry, C. R. (In Process). Survival and growth of pitch, loblolly, and pitch x loblolly pine hybrid seedlings with *Pisolithus* ectomycorrhizae on coal spoils in Alabama and Tennessee.

Table 1.--Survival and growth of loblolly and pitch pines and their hybrids with *Pisolithus tinctorius* after two and one-half growing seasons on coal spoils in Tennessee and Alabama

Ectomycorrhizae	Survival	Height	Root-collar diameter	PVI[1/]
	%	cm	cm	(x 10^2)
		Tennessee [2/]		
Pt	85	79	3.0	133
NI	81	53	2.0	43
		Alabama[3/]		
Pt	66	67	3.0	96
NI	56	43	1.6	20

1/ Plot Volume Index (PVI) computed by (root collar diameter)^2 x height x number of surviving seedlings per plot.

2/ Means of nine pine lines.

3/ Means of six pine lines.

BORROW PITS

Borrow pits created by surface-mining to supply fill for construction of buildings, dams, and highways often become severely eroded and gullied without sufficient vegetative cover. The subsoil exposed in these pits is often less toxic but lower in essential nutrients than coal mine spoils. A combination of cultural practices and planting of containerized pine seedlings colonized with Pt will result in successful reforestation of such areas.

I conducted a study on a borrow pit at the Savannah River Plant near Aiken, South Carolina (Ruehle 1980). In June 1975 the site was graded level, subsoiled to a depth of 1 meter, and double disked to break clods and smooth ridges created by the subsoiler. In September, 30 plots (7.3 x 7.3 m) were arranged with a 6-meter buffer zone separating all plots. Processed sewage sludge was broadcast over 15 plots (approximately 1.3 cm deep); 560 kg/ha of 10-10-10 fertilizer and 2240 kg/ha of dolomitic limestone were broadcast over the remaining 15 plots. All plots were double disked to a depth of 10 to 15 cm to incorporate the amendments and seeded with fescue (Kentucky 31). The following year containerized loblolly pine seedlings (one group inoculated with Pt, one group with Tt, and one group nonmycorrhizal controls) were planted by hand to establish 25 trees per plot.

The effects of the sludge and Pt were dramatic. After 2 years in sludge plots, seedlings with Pt ectomycorrhizae had 265 and 528 percent greater plot volumes than seedlings with Tt or no ectomycorrhizae at planting. As a group, seedlings on sludge plots had 900 percent greater plot volumes than those on fertilizer plots. After 4 years each plot was thinned to 9 to 12 trees with an approximate spacing of 1.7 m betwee trees. Trees on sludge plots averaged two times more height and root-collar diameter and 17 times more tree volume than trees on fertilizer plots (Table 2). The Pt-sludge treatment was still strikingly superior to other treatments. Trees on Pt-sludge plots averaged 3.4 m in height and 10 cm in diameter compared to trees on Pt-fertilizer plots which averaged 1 m in height and 3 cm in diameter.

Table 2.--Growth of containerized loblolly pine seedlings with specific ectomycorrhizae after 4 years on a borrow pit in South Carolina

Amendment	Mycorrhizal condition at planting	Height	Root-collar diameter	Tree volume[1/] (x 10^3)
		m	cm	cm^3
Sludge	Pt	3.4a[2/]	9.8a	35.0a
	Tt	3.3a	8.1b	20.3b
	Control	2.5a	7.6b	16.8b
	$\overline{X}$	2.7	8.4	20.0
Fertilizer	Pt	1.0a	3.2a	1.5a
	Tt	0.9a	3.1a	1.3a
	Control	0.7a	2.2a	0.5a
	$\overline{X}$	0.9	2.8	1.1
Percent differences between groups		2.1*[3/]	200*	1718*

1/ Tree volume (cm)^3 = (root collar diamete x height.

2/ Each mean in a column within groups followed by a common letter is not significantly different at the *P* = 0.05 confidence level.

3/ *Denotes significant differences (*P* = 0.01 between groups according to Student's t-test

CONCLUSIONS

This discussion and previous reviews by Marx (1976, 1977, 1980) leave little doubt that *Pisoli* *tinctorius* ectomycorrhizae on pine seedlings remarkedly improve our chances for successful forestation of untreated coal spoils. In all of the Institute for Mycorrhizal Research and Development research on coal spoils the Pt inoculum employed was produced in small quantities on highl defined medium under controlled conditions in a research laboratory. For commercial use, large volumes of functional inoculum are required. In 1976 the Mycorrhizal Institute joined with Abbott Laboratories[1/] to devise means of producing

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1/ Dr. Donald S. Kenney, Section Head, Microbial Products Research, Abbott Laboratories, Oakwood Road, Box 173, Long Grove, Illinois 60047 vermiculite-based vegetative inoculum of this fungus in large fermentors. After 5 years of testing different formulations of inoculum in over 40 nurseries in 33 states and Canada, adequate procedures are now available for commercially producing functional inoculum.

Much of our previous knowledge about afforestation of such sites is only of limited benefit now that federal requirements for current coal surface mining areas involves something approaching "original contour" conditions (Medvick 1980). Although we can now avoid some of the problems encountered in the past on raw spoils, the planting of trees on restored and topsoiled mine surfaces presents a new set of problems we must cope with. Numerous opportunities exist for meaningful research on coal spoils. We need to learn if companion grass cover near pine seedlings will have to be controlled with herbicides to reduce competition with trees, particularly when containerized pines are used. Should we select alternative herbaceous species and adjust their time of establishment in relation to tree planting to improve survival and growth of planted trees? Could other ectomycorrhizal fungi be isolated and used to provide benefits similar to those obtained from Pt for pine seedling survival and growth on topsoiled spoils? It seems our problems are no fewer, they have simply shifted to new dimensions. Research efforts should continue to develop mycorrhizal technology for coal strip mine reclamation.

Our studies on borrow pits, both with bareroot and containerized pine seedlings, make it clear that an integrated program of cultural and vegetative methods is required for amelioration and successful afforestation. Subsoiling, organic amendments, grass cover, and mycorrhizal tree seedlings are all needed in a unified program to transform borrow pits to productive land for trees, wildlife, and watershed management.

LITERATURE CITED

Barnett, J. P.
1980. Containerized seedlings for difficult sites. Proc. Reforestation of Disturbed Sites, Texas Agric. Ext. Serv., Texas A&M University.

Marx, D. H.
1976. Use of specific mycorrhizal fungi on tree roots for forestation of disturbed lands. pp. 47-65. *In* Proc. Conference on Forestation of Disturbed Surface Areas, Birmingham, Ala., April 14-15, 1976.

Marx, D. H.
1977. The role of mycorrhizae in forest production. pp. 151-161. *In* TAPPI Conference Papers, Annual Meeting, Atlanta, Ga., February 14-16, 1977.

Marx, D. H.
1980. Role of mycorrhizae in forestation of surface mines. pp. 109-116. *In* Proc. Trees for Reclamation Symposium, USDA For. Serv. Gen. Tech. Rep. NE-61.

Marx, D. H., and J. D. Artman.
1979. *Pisolithus tinctorius* ectomycorrhizae improve survival and growth of pine seedlings on acid coal spoils in Kentucky and Virginia. Reclam. Rev. 2:23-31.

Medvick, C.
1980. Tree planting experience in the Eastern Interior Coal Provence. pp. 85-91. *In* Proc. Trees for Reclamation Symposium, USDA For. Serv. Gen. Tech. Rep. NE-61.

Ruehle, J. L.
1980. Growth of containerized loblolly pine with specific ectomycorrhizae after 2 years on an amended borrow pit. Reclam. Rev. 3:95-101.

Walker, R. F., D. C. West, and S. B. McLaughlin.
1981. *Pisolithus tinctorius* ectomycorrhizae enhance the survival and growth of *Pinus taeda* on a southern Appalachian coal spoil. pp. 29-33. *In* First Biennial Southern Silvicultural Res. Conf., USDA Gen. Tech. Rep. SO-34.

FROST HEAVING OF CONTAINERIZED SUMMER-PLANTED SEEDLINGS[1]

Frank W. Woods[2]

Abstract.--Pinus virginiana and Pinus rigida were planted in early July on strip-mined areas that had been reclaimed in the spring of 1977. Tubelings of both species innoculated with Pisolithus tinctorius were slit-planted in undisturbed spoil and in prepared minisites to which amendments had been added and the spoil tumbled. Treatments were replicated on a bare area and an area seeded with grass. Seedling counts made 8 months, and 14 months after planting revealed that: Survival of both species on the bare area was better with minisite preparation than in undisturbed soil; survival on the bare site was greater than on the grassed site; frost-heave was greater in the case of undisturbed soil than in minisites; frost-heave was greater on the bare area than on the grassed area. Three growing seasons after planting, many of the frost-heaved seedlings are still alive. However, most of them have a procumbent habit and have not exhibited a strong apical dominance.

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[1] Abstract of paper presented at Southern ontainerized Forest Tree Seedling Conference, avannah, Georgia, August 25-27, 1981.

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A FIELD TEST OF CONTAINERIZED SEEDLINGS UNDER DROUGHT CONDITIONS[1]

T.E. Amidon, J.P. Barnett, H.P. Gallagher, and J.M. McGilvray[2]

Abstract.--A total of 8,960 longleaf and loblolly seedlings were planted on two sites in the late summer of 1979 and spring of 1980. The summer of 1980 was exceptionally dry, providing a rigorous test of container types under harsh environmental conditions. Significant differences were found among containers and between sites and species for both the fall and spring plantings. There was a significant container-species interaction in the late summer planting but not in the spring planting. Containerized seedlings survived better than bare root controls for both species.

INTRODUCTION

The major objective of this study was to evaluate the survival and early performance of containerized loblolly and longleaf pine seedlings produced in commercially available containers and prepared by typical operational techniques. Four container types, two soil types, and two planting seasons were considered. Plantings were made in August and September 1979 and March 1980 in both Kurthwood, Louisiana and Jasper, Texas. One growing season survival was used as the primary indicator of performance. Measurements of height growth and root collar diameter of loblolly and longleaf pine, respectively, were also taken. In this region, the 1980 season was characterized by a severe drought causing extensive losses in the spring 1980 plantings and dramatizing the advantages of the seedlings that were planted in the fall 1979 and established prior to the onset of stress in the summer and fall of 1980.

MATERIALS AND METHODS

Containers

Styroblock 8's (S8)

These styrofoam block containers were supplied by Silvaseed of Roy, Washington. This container has a soil capacity of 8 cubic inches, a depth of 6 inches, a top diameter of 1.55 inches, and a density of 41 cavities/sq. ft. Culture time for both loblolly and longleaf was 20 weeks in this container after an approximate, 2 week germination period. Seedlings were planted 21 weeks from seeding at the Louisiana site, and 23 weeks from seeding at the Texas site in the fall planting. In the spring planting, seedlings in this container were planted 20 weeks after seeding.

Styroblock 4's (S4)

These styrofoam block containers are from the same manufacturer as Styroblock 8, with a soil capacity of 4 cubic inches, a depth of 5 inches, a top diameter of 1.2 inches, and a density of 75 cavities/sq. ft. Culture time for both loblolly and longleaf for the fall planting was 17 weeks after seeding for the Louisiana site and 19 weeks after seeding for the Texas site. In the spring planting, culture time was 17 weeks from seeding for both sites.

Kys-Tree-Start™, K-7 (Kys)

This is a triangular sided compressed block manufactured by Keyes Fiber Company, New Iberia,

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[1] Paper presented at The Southern Containerized Forest Tree Seedling Conference, Savannah, Georgia, August 25-27, 1981.

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Louisiana. This container has a 4.5 cubic inch capacity, is 1.25 inches/side, and 5 inches tall. The block was composed of sphagnum peat moss, vermiculite, cellulose fibers, a wetting agent and fertilizer (23, 10, 15 with diammonium phosphate, potassium nitrate, and ammonium nitrate) at a reported pH of 5.5-6.5. This container was only planted in the late summer 1979 due to greenhouse culture problems. Seedlings in this container followed the same greenhouse culture as Styroblock 4's.

Todd® Model #150-50 (Todd)

These are styrofoam block containers supplied by Speedling, Inc., Sun City, Florida, USA. They are pyramid shaped containers with top dimensions of 1-1/2 inch square and a depth of 5 inches, with a container capacity of 3.7 cubic inches and a density of approximately 50 cells/sq. ft. This container was used in the spring planting to replace the Kys-Tree-Start container, and followed the same culture regime as Styroblock 4's.

Greenhouse Culture

All containers (except Kys-Tree-Start) were filled with 1:1 screened peat and vermiculite. They were seeded with cold stratified loblolly seed or unstratified longleaf seed that were surface sterilized by a 24 hour soak in 3% H_2O_2 prior to seeding. Seeded containers were placed under a mist system for two weeks to facilitate germination. Fertilization began when seed coat dropped, approximately 3 weeks after seeding. The fertilizer, Peter's 20-19-18 at 150 ppm N, was applied twice a week, weather permitting. A preventative Benlate treatment of 1 rounded tsp/gal was applied once every 2 weeks. Supplemental light was applied to longleaf seedlings during greenhouse development for the spring plantings.

Seed

Loblolly

International Paper Company improved seed lot, southern loblolly large, Springhill, Louisiana orchard, 1978.

Longleaf

Department of Natural Resources, Columbia Nursery, Columbia, Louisiana, 1970.

Bare Root Seedlings

Both loblolly and longleaf seedlings were sown April 30, 1979 at International Paper Company's Natchez nursery. Loblolly seedlings were lifted and cold stored until time of planting under standard nursery practice. Longleaf seedlings were lifted less than one week prior to planting and cold stored until use.

Crop Specifics

Late Summer Planting (8/79)

Styroblock 8 seeding date (4/6/79)
Kys-Tree-Start and Styroblock 4 seeding date (5/4/79)
Planting date - Kurthwood, Louisiana (8/28/79)
Planting date - Jasper, Texas (9/12-13/79)

Spring Planting (3/80)

Styroblock 8 seeding date (10/15/79)
Todd and Styroblock 4 seeding date (11/13/79)
Planting date - Kurthwood, Louisiana (3/11/80)
Planting date - Jasper, Texas (3/13/80)

Site Description

Kurthwood, Louisiana

Soil series - Susquehana-Sumter-Houston Association (sandy loam). This was a level site with good site index (>80) and a relatively high water table.

Jasper, Texas

Soil series - Letney-Tehran loamy sand. This was a deep sand, dry site, with a 1-8° slope and a low site index (≈70).

Statistical Analysis

The effect of different container types upon survival rate and the growth of the surviving trees was investigated for four combinations of species (loblolly, longleaf pine) and planting season (spring, late summer). Each of the four combinations was analyzed as a standard split-plot design with the site (Texas, Louisiana) serving as the whole-plot factor and the container type as the split-plot factor. Four replications (each an 80 seedling plot) of every treatment combination were performed in each analysis.

The survival proportion (p) in each replication was transformed to $y=\text{ARCSIN}\sqrt{p}$, a standard transformation for proportions, before the analysis was done. The site effect was tested against the whole plot error, while the container and the site by container interaction effects were tested with the split-plot error. Site and container effects were tested at the 0.05 significance level. When there was no site by container interaction, the least significant difference method, at a significance level of 0.05, was used to order the containers by mean survival rate ($\bar{y}$).

Growth measurements were taken on the surviving trees of both species: root collar diameter on the longleaf and height for the loblolly. These measurements were averaged for each replication and used as the response variables in the same type of split-plot design described above.

RESULTS AND DISCUSSION

Container Influence on Survival

Overall survival in the late summer planting in this study showed a highly significant container effect (Table 1). Seedlings grown in

Table 1.--Container survival by site, species, and planting time (%).

	Late Summer						
	Loblolly (a)			Longleaf (b)			Container
Container*	LA	TX		LA	TX		Average
Kys (b)	84	58	(b)	70	38	(c)	63
S4 (b)	80	70	(a,b)	70	66	(b)	72
S8 (a)	85	77	(a)	88	77	(a)	82
Site Average	83 (a)	68 (b)		76 (a)	60 (b)		
Grand Average							72

	Spring						
	Loblolly (a)			Longleaf (b)			Container
	LA	TX		LA	TX		Average
Bare Root	7	43	(b)	1	6	(c)	14
Container*							
Todd (a)	33	60	(a)	8	29	(b)	33
S4 (a)	37	70	(a)	5	31	(b)	36
S8 (a)	23	66	(a)	12	44	(a)	36
Site Average	31 (b)	65 (a)		8 (b)	35 (a)		
Grand Average							35

*Denotes significant difference across species. Lower case letters (a,b,c) indicate statistically significant differences; those with same letter are not statistically different at α0.05.

Styroblock 8 containers survived better than those in Styroblock 4 containers by an overall difference of 10% and in the Kys-Tree-Starts by an overall 19%. A significant site effect was seen with Texas survival lower than Louisiana for all container types (Table 1). No significant site-container interaction was found in this planting.

In the spring planting, no significant differences were found between containers. All containers showed significant increases in survival over bare root controls. Bare root seedlings averaged 14% survival, Todd 33%, and the Styro 4's and 8's 36% (Table 1). A significant site effect was found in this planting with the Texas site yielding better survival. This is the reverse of late summer data in which the Louisiana site performed better.

Survival Differences Between Species

There was a highly significant difference between species, with loblolly surviving better (Table 1). A significant species-container interaction was found in the late summer planting, but none was found in the spring planting. This significant species x container interaction stems rom equivalent survival for both species in the late summer planted S8 container, while in the other containers loblolly survived better than longleaf. In the spring planting, loblolly always urvived better. Thus longleaf survival was ompetitive with loblolly when late summer planted n S8 containers.

Analysis of data segregated by species showed significant differences for loblolly between the S8 and Kys containers in the late summer planting (Table 1). No significant difference is seen between S4 and S8 or S4 and Kys in the late summer planting. In the spring planting, there were no significant differences among containers in loblolly survival. However, all containers performed significantly better than bare root seedlings.

Analysis of longleaf survival data showed a significant difference between all 3 containers in the late summer planting with the ordering S8> S4>Kys. In the spring planting a significant difference was noted between the S8 container and the others, with no difference noted between the S4 and Todd containers. It should be noted that these results for longleaf are less certain as there is a site-container interaction in both seasons.

Preplanting Crop Status Effect on Survival

Data indicative of seedling quality were collected by random sampling at the time of planting (Table 2). Measurements were made of height, stem caliper, and top and root oven-dry weight. In longleaf seedlings, no attempt was made for a height growth indicator, rather stem caliper and oven-dry top weight were the only indicators of shoot growth. There are few seedling measurements for the Kys due to limited crop size and inability to retrieve roots for measurement.

Table 2.--Greenhouse seedling characteristics.

Loblolly									
Late Summer					Spring				
Container	Height (mm)	Stem Caliper	Top Weight (g)	Root Weight (g)	Container	Height (mm)	Stem Caliper	Top Weight (g)	Root Weight (g)
S8	210.8	3.0	1.48	0.24	S8	251	3.3	1.42	0.27
S4	206.5	2.6	0.84	0.16	S4	199	2.6	0.70	0.14
Kys	--	--	--	--	Todd	179	2.4	0.66	0.13

Longleaf							
Late Summer				Spring			
Container	Root Collar (mm)	Top Weight (g)	Root Weight (g)	Container	Root Collar (mm)	Top Weight (g)	Root Weight (g)
S8	4.8	2.19	1.82	S8	3.9	1.40	0.19
S4	2.9	0.97	0.67	S4	2.9	0.69	0.10
Kys	2.6	0.70	--	Todd	3.2	0.89	0.13

On average, Styro 8 containers produced seedlings with 93% greater root weight and 113% greater shoot weight than the other containers. Container volume and culture time cannot be separated in this study; therefore, the relative importance of these 2 parameters in the differences between Styro 8 and other containers cannot be attributed to either.

In comparing the Todd and Styro 4 containers, which experienced the same greenhouse culture, there was an interesting species interaction. The loblolly seedlings grew better in Styro 4's, whereas the longleaf seedlings showed better growth in the Todd container (as measured by top weight and root weight). This suggests that the increased seedling density of the S4 container is more detrimental to longleaf development than to loblolly, as the other container characteristics such as depth and soil volume are only slightly different between these containers.

Survival and Rainfall

The 1980 growing season was very dry across the southern United States and provided an extreme situation for testing survival. Rainfall data was obtained from the N.O.A.A. data collection sites in Jasper, Texas and Leesville, Louisiana (≈15 miles from Kurthwood planting site). The summer rainfall totals (June, July, August) were 2.83 and 3.40 inches for Jasper and Leesville, respectively. The rainfall was not evenly distributed with one rain providing over three-quarters of the total at Jasper and two rains providing almost two-thirds of the total at Leesville. At both sites, droughts of over 30 consecutive days without rainfall greater than 0.5 inches were encountered.

Survival data for the later summer planting was segregated into two time periods: (1) from planting to January 1980 and (2) from January 1980 to January 1981 (shown in Table 3). The initial mortality is attributed to transplant shock and the longer term mortality is attributed to the dry 1980 summer. In the Louisiana planting, which had moist soil at planting time, the Styro 4 container appeared more susceptible to this shock mortality than the other containers showing a 7% loss for loblolly and an 8% loss for longleaf. In the Texas planting, which had extremely low soil moisture on the planting date, the Kys container showed the highest mortality during this period with loblolly losing 22% and longleaf 30%. This difference between planting site in transplant shock may reflect the differences in original soil moisture and rainfall during September 1979 to January 1980 at those two sites: Texas, very dry initially with 15.3 inches of rainfall and Louisiana, moist originally with 21.5 inches of rainfall The very dry Texas site had higher transplant shock mortality for Kys and S4 but not for S8. S8 container seedlings exhibited the least mortality over this period, and appear to be least susceptible to transplant shock.

From the data in Table 3 for loblolly pine, the largest component of loss is associated with the 12 month period during 1980 for the Louisiana site. Analysis of these figures show no significant differences in mortality over this period associated with container, sites, or site x container interactions. Consequently, this mortality is associated with some parameter outside the planting vehicle. The low rainfall during this period is the most likely explanation for this loss.

In longleaf pine no difference between the average mortality during 1980 due to site or site x container interaction effects are evident (Table 3). However, mortality in Kys containers during this period (29%) differed significantly from that of the S8 container averaging 18% with no statistically significant difference found between the S4 container (21%) and either the Kys or the S8 container. No obvious explanation for the high mortality of the Kys container during this period is known; however, this container exhibited poorer greenhouse culture performance, and higher mortality may be a measure of seedling quality rather than a field aspect of container performance.

Table 3.--Losses over time, late summer planting.

	Planting to 1/80			
	Loblolly		Longleaf	
Container	LA	TX	LA	TX
Kys	4%	22%	4%	30%
S4	7%	16%	8%	14%
S8	4%	2%	2%	3%

	1/80 to 1/81			
	Loblolly		Longleaf	
Container	LA	TX	LA	TX
Kys	12%	20% (a)	26%	32% (b)
S4	13%	14% (a)	22%	20% (a,b)
S8	11%	10% (a)	10%	26% (a)

*Lower case letters (a,b,c) indicate statistically significant differences; those with same letter are not statistically different at α0.05.

The lack of significant differences in the loss data for late summer planted loblolly during the 12 month period of 1980 indicates that the significant (16 month) differences were due to planting shock effects during the first four months of field adaptation. Thus the Styro 8 container, either through the virtue of increased soil volume, lower seedling density, or longer culture period, was less susceptible to transplant shock than the Kys container. Analyzing the data, partitioned into these time periods, shows the importance of transplant shock stress in determining loblolly survival differences between containers. Statistically, significant differences in overall survival stem from differences during the initial acclimation period.

In longleaf, statistical differences are seen in percent loss over the period 1/80 to 1/81 with Styro 8 containers suffering less loss than the other 2 containers. This suggests that container parameters influence field performance after the initial transplant shock period for longleaf. Presumably, this effect is associated with the increased container volume and culture time of S8's.

Field Measurements as an Indicator of Container Performance

Field performance of containerized seedlings was assessed by loblolly height measurement and longleaf root collar diameter in 1/81 (Table 4). It was found that the mean height of loblolly seedlings showed a positive correlation with percent survival (R=0.59). This relationship also held for longleaf root collar (R=0.57). Thus, those containers which performed well in terms of survival also performed well in terms of growth. Height of survivors at 1/81 showed a significant site and site x container effect for both species in the late summer planting. The Louisiana site proved better for both species. The site x container interaction stems from a different ranking of the containers between Louisiana and Texas; however, the S8 outperformed the others in both sites in both species.

Table 4.--Mean height and root collar diameter of survivors (1/81).

Loblolly Mean Height (ft.)					
Late Summer			Spring		
Container	LA (a)	TX (a)	Container	LA	TX
			Bare Root	0.9 (a)	0.8 (a,b)
Kys	1.5 (b)	1.1 (b)	Todd	0.8 (b)	0.8 (b)
S4	1.4 (b)	1.3 (a)	S4	0.8 (b,a)	0.8 (a,b)
S8	1.7 (a)	1.4 (a)	S8	0.9 (a)	0.9 (a)

Longleaf Root Collar (in.)					
Late Summer			Spring		
Container	LA (b)	TX (a)	Container	LA (a)	TX (a)
			Bare Root	0.4	0.4
Kys	0.4 (b)	0.4 (c)	Todd	0.3	0.3
S4	0.4 (b)	0.5 (b)	S4	0.4	0.3
S8	0.5 (a)	0.6 (a)	S8	0.4	0.4
				No Significant Difference	

*Lower case letters (a,b,c) indicate statistically significant differences; those with same letter are not statistically different at α0.05.

In the spring planting, no significant site interaction was found for either species. A significant container effect on height measurement was found for loblolly pine with the S8 container differing from the Todd container, but not showing a significant difference between bare root or the S4 container. The lack of significant differences in height of bare root seedlings versus containerized is noteworthy as the bare root seedlings were larger on outplanting. The growth exhibited by containerized seedlings during this period decreased the initial size advantage of bare root seedlings. Longleaf showed no significant site difference and no significant differences in root collar diameter.

CONCLUSION

Data presented indicate that: (1) containerized seedlings surpass bare root seedlings in survival and can yield competitive first year growth with bare root stock; (2) of the containers tested, the Styroblock 8 container showed the best performance for both species in both seasons; (3) late summer planting of containerized longleaf can yield results competitive with loblolly, and both species can yield acceptable survival when planted at this time even when the subsequent year is very dry; (4) longleaf is more sensitive to container parameters than loblolly as indicated by significant differences in survival between containers when comparable data for loblolly fails to show significance; and (5) in late summer planted loblolly, the mortality during the initial stress period (4 to 5 months) differentiated container types, while subsequent mortality was not significantly affected.

ACKNOWLEDGEMENT

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USE OF CONTAINERIZED SEEDLINGS FOR PROGENY TESTING[1]

J. P. van Buijtenen[2] and W. J. Lowe[3]

Abstract.--Nine of the twenty-one WGFTIP members are using containerized seedlings for part of their progeny testing. The main advantages are increased uniformity, quicker turn-around, more plantable seedlings for a given number of seeds, and greater ease of field planting. Growth has been comparable to that of bare-root seedlings.

INTRODUCTION

During the past few years, the use of containerized seedlings for the purpose of progeny testing has increased greatly. About six years ago, progeny tests were established exclusively from bare-root seedlings. Now nine of the twenty-one members of the WGFTIP program are using containerized seedlings for at least part of their progeny testing. Also, all of the progeny testing for the Texas Urban Tree Improvement Program utilizes container grown seedlings. Types of containers used vary greatly, but styroblocks, speedling flats, and Ray Leach tubes are among the ones used most commonly. The N. C. State Cooperative and the Florida Cooperative are making only limited use of containerized seedlings for progeny testing.

ADVANTAGES OF USING CONTAINERIZED SEEDLINGS FOR PROGENY TESTS

Increased Uniformity

This is by far the most important consideration in using containerized seedlings for progeny testing. No matter how well a nursery bed is prepared, the seedlings in the nursery bed are usually far from uniform. Differences in germination, soil texture, low spots in the nursery bed, leakage from irrigation systems, and problems with weeds all contribute to this lack of uniformity. That doesn't imply that containerized seedlings are automatically uniform because they have problems, too. For instance, we have noticed some pronounced edge-effects, but with proper management, very uniform seedlings can be produced. As with any greenhouse operation, very close attention needs to be paid to watering schedules, fertilizer programs, and insect and disease control. Damage can easily occur in less than 24 hours if a problem remains undetected or untreated. Because of the edge-effects and other differences in a greenhouse climate, it is as important to replicate the seed lots for a progeny test in a greenhouse as it is in a bare-root nursery.

Quicker Turn-Around

If a program is managed efficiently, it is possible to collect seed from controlled loblolly pine crosses in the fall, stratify the seed, plant them in a greenhouse in late November, and field plant the seedlings in April. This essentially gains one year, compared to bare-root seedlings, which would be planted in the nursery in April and the seedlings field planted in the next dormant season. The process is more easily attained with species, such as slash pine, that require little or no stratification period. This is a very important consideration in a tree improvement program where a reduction of the generation interval results in an increased gain per unit of time.

More Plantable Seedlings for a Given Number of Seed

Even with the extra care given to progeny test seedlings in the nursery, we generally need to plant between two and three seeds for every plantable seedling desired. In a recent test carried out by the Texas Forest Service, germination percentage in the nursery varied by family and ranged from 31 to 74 percent for slash pine and 38 to 91 percent for loblolly pine. Using containerized seedlings in Leach tubes, it is possible to get 99 plantable seedlings out of 100 seeds, although this is quite unusual. Normally, we plan to use 150 seeds to obtain 100 plantable seedlings when using styroblocks or speedling flats. We generally do some transplanting or double seeding. When using controlled crosses of which only a very limited number of seeds are available, the seedling percentage is extremely important. It has been possible in some cases to avoid an extra year of crossing efforts because of the increased proportion of plantable seedlings.

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[1] Paper presented at Southern Containerized Forest Tree Seedling Conference, Savannah, Georgia, August 25-27, 1981.

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With species for which it is difficult to obtain a high percentage of sound seed, we usually sow the seed in petri dishes or on trays. Only germinated seed are planted in the containers. This practice increases the proportion of good seed that are used and eliminates the need for multiple sowing, thinning, and later transplanting. Also, it is easier to obtain a uniform growing density. Large seeded species, such as the oaks, that present special problems in multiple sowing and transplanting also work well with this system.

Greater Ease of Field Planting for Complex Designs

With certain kinds of containers, particularly movable containers such as the Ray Leach tubes, it is possible to re-arrange the seedlings prior to field planting in exactly the way they need to be set out in the field. This process is not usually weather dependent such as lifting seedlings from a bare-root nursery. Also, it can be completed before the tests are to be planted which enables easier scheduling of personnel and activities. This greatly simplifies and speeds up the establishment of progeny tests in the field. The more complex the design, the greater the benefit of the use of containerized seedlings.

DISADVANTAGES OF USING CONTAINERIZED SEEDLINGS

Difference from Operational Practices

The use of containerized seedlings is another step further away from operational practice. Many years back, when tree improvement started, the philosophy was that progeny tests should be treated exactly like operational plantings. As time went by, we have drifted away from this practice primarily because progeny tests need to be uniform in order to be effective in distinguishing between fast and slow growing families. For the sake of uniformity, progeny test sites are now much better prepared before planting and also receive better maintenance than operational plantings. The use of containerized seedlings carries this one step further which may affect the rankings of the families. One could visualize, for instance, that the ability to regenerate a root system after lifting is an important attribute of a bare-root seedling, while it is not a significant factor for containerized seedlings. This could possibly affect its performance.

Slower Initial Growth

In a number of instances, containerized seedlings appear to have a slower start than bare-root seedlings. This may be partially due to the somewhat smaller size of the containerized seedlings and partially due to the fact that containerized seedlings do not develop side roots in the top six inches of the soil because of the root structure inside the containers. Eventually, they seem to get over this.

Length of Planting Season May Not Be Increased

One of the advantages that is often quoted in favor of the use of the containerized seedlings is that it increases the length of the planting season. This is true if sufficient soil moisture is present and the seedlings are properly hardened off. However, in our experience, the planting season for pine seedlings in containers is distinctly different from bare-root seedlings, but carrying out the planting operation in the proper time slot seems to be even more critical. We find that we can plant pine seedlings only at two periods of the year, in early spring and early fall. First of all, we need to wait until the danger of frost is over. Then we need to plant well before the usual summer drought unless irrigation is available. This means that, in effect, we need to plant our seedlings between March 15 and April 15. In the fall, we have another time slot in which we can plant. In this case, we need to plant after the fall rains have restored soil moisture, but at least one month before the first hard freeze. For practical reasons, in effect, we cannot plant trees until the cone collecting season is over, which leaves a period from the middle of October until the middle of November. The last seedlings planted may get burnt badly by an early freeze, although they usually recover in the spring.

Planting activities start for the hardwood seedlings in the fall when sufficient soil moisture is available which usually occurs in September. This activity can continue through the winter until the middle of April. As with the pine seedlings, the chance of summer drought is our main concern after this time. Dormancy and winter burn do not cause a major problem with the hardwood species.

Because of the extended summer droughts in our area, we are cautious about extending planting activities too late into the spring. In areas where rainfall patterns are more uniform, extension of the planting season into the summer should be feasible. Also, different procedures for hardening of pine seedlings may reduce our problems with winter burn.

PRACTICAL CONSIDERATIONS FOR PRODUCTION OF CONTAINERIZED PROGENY TESTS

When developing a schedule for the production of containerized progeny tests, it is important to determine the desirable field planting time and then develop a management program that will allow acceptable quality seedlings to be produced at the desired date. Factors such as the size and type of the container, greenhouse management, and practical limitations dictated by seed collection and stratification requirements for a species need to be considered. If an improper management regime is used in the greenhouse, the seedlings can be too small at the desired planting time for survival or be unable to compete with existing vegetation at the planting site. Also, the seedling root system may be underdeveloped so that it can not be pulled from the container. By the same token, they can be grown too large for the container which will cause an imbalance between the top and the root system. This usually results in rootbinding that will handicap growth and later performance in the field.

Currently, styroblocks, speedling flats, and Ray Leach tubes are among the most commonly used containers for progeny test production. Early in our containerized program, we attempted to use other types of containers, such as the bag and tube type of containers. Neither of these types of containers performed satisfactorily under our conditions. The main problem that we experienced with both of these containers was root spiraling. Also, with many of the tube type of containers, the tube material did not decompose soon enough when it was field planted so that the root system could penetrate into the soil.

There are several different types of media that are available for use in a container program. Under our conditions, a mixture of 1:1 peat moss and grade four vermiculite is an acceptable growing media. Fertilizer can either be incorporated into the media when it is being mixed or it can be applied by injection through the irrigation system. Either technique or a system that utilizes both methods of fertilizer application is satisfactory. It is important to note that if fertilizer is injected through the irrigation system, you need to continue watering after fertilization has stopped to wash the fertilizer off the leaf surface. If this is not done, it is possible to develop a salt accumulation on the leaves which will damage the seedlings.

Intermittent supplemental lighting at night can be used to increase stem elongation. If supplemental lighting is used, the seedlings will have a tendency to become very spindly. The supplemental lighting needs to be stopped and the fertilization regime changed prior to outplanting so that sufficient seedling caliper can be developed. Many of our southern species will grow fast enough in containers to obtain an acceptable seedling without the use of supplemental lighting.

It is common knowledge that bare-root seedlings need to be planted sufficiently deep. This is also an important consideration with containerized seedlings. The growing plug needs to be planted completely below the surface of the soil. If a portion of the plug is left uncovered, it can act as a wick to dry the root system of the seedling out.

SOME ACTUAL FIELD EXPERIENCES WITH CONTAINERIZED PROGENY TESTS

The Texas Forest Service has not planted containerized and bare-root seedlings in the same test. We do, however, have some tests of both kinds established in the same year. Table 1 gives a comparison of several tests established in the 1974-75 and 1975-76 planting seasons. Tests 1 and 2 contained very similar materials. One planted in 1974-75 from bare-root seedlings, the other planted in 1975-76 from containerized seedlings. The difference in growth, however, cannot necessarily be attributed to the use of containerized seedlings. Plantation 3 was the only other loblolly plantation established in the same year, and had very similar growth to the containerized seedlings. The comparison is somewhat arbitrary, however, since the two tests were planted at two rather widely separated locations.

Table 1.--Plantation summary for bare-root and containerized loblolly pine progeny tests

	1974-75 Bare-Root	1975-76 Containerized	1975-76 Bare-Root
	1	2	3
Survival at age 1 (%)	98.0	98.1	97.1
5-Year Height (m)	4.18	3.89	3.86
5-Year DBH (cm)	5.62	4.71	4.92
5-Year Volume/Tree (dm^3)	3.89	2.50	2.88
Rust Score	.692	.707	.977
Rust Infection (%)	27.5	25.4	37.1
Survival at age 5 (%)	96.6	94.5	94.6

During the 1975-76 planting season, six live oak progeny tests were established in areas outside the natural timber range. Half of the tests used bare-root seedling while the other half were established with containerized seedlings. First year survival for the bare-root tests averaged 64 percent (range 44-86 percent) while the containerized tests averaged 85 percent (range 79-97 percent). First year survival of progeny tests established in this area is very dependent upon test management. However, the use of containerized seedlings has significantly increased the average first year survival.

SUMMARY

During the last few years, the trend has been toward using containerized seedlings for the production of progeny tests. Containerized seedlings have the advantages of increasing test seedling uniformity, more efficient use of seed, a reduction in time required to establish progeny tests, and the simplification of field planting procedures. Possible disadvantages are that in some cases it appears that containerized seedlings have slower initial growth, and the use of containerized seedlings is a different practice from operational regeneration programs.

FUTURE OF GREENHOUSE CONTAINER
NURSERY SYSTEMS IN THE SOUTH[1]

Richard W. Tinus[2]

Abstract.--Greenhouse container nurseries' contributions in the South include superior seedlings for specialty crops, longer planting season, promoting mechanization, and conserving valuable seed. Future greenhouses must be more energy efficient, and growing systems may change drastically. Past mistakes include lack of clear objectives and a systems approach, overly complicated and expensive structures, using too small a container, and poor administrative decisions and organization. These mistakes can be avoided by applying current knowledge.

ADVANTAGES IN THE SOUTH

The South is the last major tree growing region on the North American continent to embrace the greenhouse container nursery system as a major reforestation tool, probably because nowhere else is the bare root option so cheap and satisfactory. Currently, the greenhouse container nursery is used in this region mainly for specialty crops, such as longleaf pine, sand pine, Fraser fir, oaks, and eucalypts. The number of species grown probably will increase with the demand for diversification in the forest and as more uses for the different species are found.

In addition, there will also be increased use of the greenhouse container system for producing the main crops of loblolly, slash, and shortleaf pine, for three principal reasons (Tinus 1975). First, it extends the planting season. Bare root stock can be used only for a small portion of the year (Xydias 1981). The 3-month bare root planting season is too short to satisfy the growing reforestation job in the South. The container system offers the potential to plant throughout the year in many parts of the South. Second, the handling of nursery stock in the nursery, in transit and storage, and particularly in planting needs to be more completely mechanized. Because the container seedling is a standard package, it is probably easier to mechanize than the handling of bare root seedlings. Third, increasing numbers of seedlings in the South are grown from genetically improved seed. At $1,100 per kilogram value, it is important to produce maximum number of seedlings. In the greenhouse, expensive seed will not be washed out of the ground by torrential rains or devoured by blackbirds.

SOURCES OF INFORMATION

Although certain aspects of production problems in the South are different from those in other parts of the continent, there is still a great deal of commonality among container nursery problems. Southern container nurserymen can learn much valuable information from their counterparts elsewhere. Today there is enough information available so that anyone who studies the subject and plans well should not make any catastrophic errors (Tinus and McDonald 1979). Ten years ago that was not the case.

IMPORTANCE OF ESTABLISHING OBJECTIVES

To properly realize the benefits of the greenhouse container nursery system, it is necessary to have objectives clearly in mind. For example, in the Southwest there are two planting seasons: one in February and March, and one in August. Tree planting success in the early spring season has generally been low, because the planting season is invariably followed by a drought. The rains come in late summer. Seedlings have a good chance to get established, but bare root stock is not available then.

Here is how two organizations responded to the opportunity. Organization A began building a new nursery complex that was to include both a bare root and a container nursery. The design of the greenhouse system was contracted to an architectural firm with instructions that it be solar heated, highly mechanized, and quite permanent. After spending $250,000 on the design, it became obvious it would not be able to afford seedlings produced in such a facility, so the entire container nursery was scrapped. Development of the bare root nursery went ahead on schedule, but the organization was again locked into an early spring planting season. Just as every bare root nursery has problems unique to it which require research effort to make the operation a success, the Organization A nursery has a host of cultural problems yet to be solved before it will be able to grow high quality stock reliably. In contrast, the technology for growing container seedlings in greenhouses is much more easily transferred. With properly informed, competent help it is quite possible to do things right the first time.

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At the same time, Organization B built a single, medium-sized, inexpensive greenhouse. It began growing pine in large containers and planted it in August with very high survival. The nursery and planting effort has grown tremendously since then, and the seedlings' initial survival and growth rates have been very high.

There are several lessons to be learned here. First of all, if someone nearby is doing something that works, don't be afraid to copy it, even if your own organization has the reputation for being the leading expert. Second, don't overdesign or overbuild. It is not necessary to have an expensive installation to grow fine container seedlings. Third, have your objectives clearly in mind. Organization A didn't know what it wanted from the container system, but Organization B did.

TAKE A SYSTEMS APPROACH

Whether you have a bare root or container system, believe in it. Take a systems approach, and do everything right, not just part of it, because attitude creates a self-fulfilling prophecy. To illustrate, Organization C had a successful bare root operation. Its nursery produced high quality stock. It was very careful about maintaining stock in good condition during transportation to the planting site. Its planters were well trained and highly motivated, and as a result establishment success was high. It also had a container operation, sort of an adjunct to the nursery stuck in a corner. The container stock produced was mediocre. It was shipped to the planting site with little allowance for the fact that it had to be treated differently than bare root stock. The planters grumbled about having to carry the extra bulk and weight, and the seedlings were so small they didn't look important. Sure enough, the bare root stock outperformed the container stock every time.

CONTAINERS AND STRUCTURES

Start with a large enough container. It is better to start with one that is big enough, even if it looks too expensive. If there is time, run some small scale field trials. After you succeed, then see if a smaller one will do. Frequently, a variety of sizes will be needed to handle differen species and different planting sites.

Don't overbuild (Guldin 1981). Plan with the expectation that any facility built now will be obsolete in 10-15 years. Too many facilities are built of steel, concrete, and glass designed to last forever. Although greenhouse container technology is maturing to the point where there is enough information to do a good job reliably, some major changes are coming. Greenhouse production of seedlings is an energy intensive process, especially for winter crops, and a great deal of research is in progress to find ways to insulate greenhouses, make maximum use of solar heat, and modify growing regimes to conserve fuel. Make sure that any system built now has the flexibility to retrofit to a more energy efficient system later, or be prepared to scrap the whole thing and build a new one.

In addition, there is the prospect of entirely new growing systems. In nursery systems now in widespread use, container shape and air pruning control the root system configuration. Air pruning requires that the bottoms of the containers be exposed to circulating air. Therefore, the seedlings are grown on benches or tables. The greenhouse is heated most conveniently by a forced air system which makes air temperatures fairly uniform throughout the house. Dr. Carl Whitcomb, Oklahoma State University, has described experiments in which the greenhouse is floor heated, but the air is not. The seedlings are grown directly on the greenhouse floor. According to him, this results in a great saving in fuel costs, because the heat is applied to the seedlings and the air in the greenhouse is allowed to remain cold. The cold air loses far less heat to the outside than warm air. To use a floor heat system, you must get away from air pruning. Burdett (1978) and McDonald, Tinus, and Reid (1980) have described successful experiments in which root configuration is controlled by copper carbonate in latex paint on the container wall. With this technique, it may be possible to grow seedlings with a desirable root configuration without air pruning. Further, seedlings on the floor could be subirrigated, which would eliminate continual wetting of the foliage with nutrient solution and would greatly reduce the incidence of Botrytis, a foliage mold which is a serious pest in the Pacific Northwest and likely to be one in the Southeast. If this new system is found to be feasible and possibly superior to the current system, greenhouses and containers will be quite different from what they are today.

Another reason for not overbuilding is that reforestation is a long-term effort which should be kept at a fairly even level in the face of short term ups and downs in the economy. Administrators should concentrate on function and cost effectiveness and not become enamoured with structure. For example, Organization D built a very modest-appearing facility on the West Coast and took full advantage of the maritime climate to use minimum environmental control. It produced one crop per year. Much of the equipment was home-made and not fancy, but it worked well. The operation has grown, and the staff have become consultants to other companies up and down the West Coast.

In contrast, Organization E built a very expensive system, heated by electric boilers and with 7,000 lux of sodium arc lights. It produced two crops a year and tried to produce three. All of the equipment was the finest available, but several years ago, management decided it couldn't afford it any more. The capital cost per seedling produced was too much. The company still operates the facility, but produces seedlings on contract to other companies.

Finally, Organization F planned a greenhouse facility in the far North that was to produce three crops a year under fully controlled conditions, including sodium arc lights. The irrigation water was to be pumped from a river 3 km away. A natural gas pipeline would run a generating plant to produce electricity for the complex. When the price tag reached 20 million dollars, they asked me "Will it work?" I said, "Yes, it is biologically sound, but can you afford it?" After some soul searching, they decided they couldn't. Instead, they built a much more conventional greenhouse system for one crop per year, and the results, as far as I know, have been very satisfactory.

Be sure your architects and engineers have designed successful tree growing greenhouses before. Some years ago, Organization G built a greenhouse nursery system. It was a conventional fiberglass structure which the manufacturer had sold all over the country, but their structures apparently had not encountered the winds of the Great Plains. After losing pieces of roof several different times, they were convinced to eliminate the eaves and fasten the roof with lengths of electrical conduit rather than individual screws or nails. This same greenhouse was designed with an overhead polytube system. The upper echelon architects would not approve a structure so flimsy as polyethylene, so this became a $3,000 steel air duct which was good for shade, but not much else. During cold weather, the heating system did an excellent job of keeping the top of the greenhouse warm, but failed to maintain growing temperatures at plant level. Eventually, the heating system was rearranged and the air flow placed at floor level where it belonged.

Whatever you do, keep the design as simple as possible. There will be less to go wrong, and it will be cheaper and easier to fix if it does, especially when the equipment gets old. Make sure you have service for your equipment nearby, and spare parts for all essential pieces on hand.

MANAGING PEOPLE

Some of the most common problems in nursery operation are managerial, rather than technical. Several measures can be taken to avoid these "people problems."

Reforestation should be under a single unified management. Especially in organizations that do the whole job, one person should be in charge of the nursery, the transportation, the planting, and stand establishment. That way everyone is more likely to act as a team working together to solve problems rather than shifting the blame to someone else, or solving one's own problems at the expense of making someone else's more difficult.

There should be a clear line of authority. No one except the greenhouse operator should change the dials or apply treatments to the seedlings. If a higher level manager sees something wrong, the one directly in charge should be told to make the necessary changes; the manager should not make them himself.

Have the right kind of expertise where you need it. A horticulturist or equivalent should be in charge of the greenhouse, and should not be assigned purchasing, hiring and firing, and other paperwork which detract from greenhouse duties.

If the system works, don't change it. Any proposed change should be tested in a small way before it is applied to the entire nursery. Remember that a nursery's function is to guarantee on-time delivery of a specified number of high quality seedlings. Leave the research to researchers. Unfortunately, it is not uncommon that after two successful crops a nurseryman may think he is an expert and entitled to remold the growing regime at will. Frequently, when I am called upon to help, I find the nursery is no longer doing the things that originally made the operation successful.

Know when to seek advice. Do not let problems become disasters before asking for help. An expert consultant should be giving you a system, not just a patch. If the first expert doesn't tell you what you want to hear, by all means get a second opinion. The second expert may give you something different and perhaps equally good, but select one of the systems and don't mix the two. There are many right ways to do things, but not all of them are compatible with each other.

It is sometimes hard for administrators to recognize good advice and act on it. They frequently don't know when they need to buck their own organization to get things done right. Too often new container nurserymen or administrators will accept poor decisions without realizing the consequences until major problems develop.

If you do all of the things I have suggested, your success may not be guaranteed, but at least you can begin making original mistakes immediately.

LITERATURE CITED

Burdett, A. N.
1978. Control of root morphogenesis for improved mechanical stability in container-grown lodgepole pine. Can. J. For. Res. 8:483-486.

McDonald, S. E., R. W. Tinus, and C. C. P Reid.
1980. Root morphology control in forest tree seedling containers. p. 40-45. In Proc. 1980 Intermt. Nurserymen's Assoc. and West. For. Nursery Counc. USDA For. Serv. Gen. Tech. Rep. INT-109, 148 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Guldin, R. W.
1981. Containerized southern pine seedling production costs. Proc. Symp. on Engineering Systems for Forest Regeneration. Am. Soc. Agric. Eng. [Raleigh, N. C., Mar. 2-6, 1981] (in press.)

Tinus, R. W.
1975. The place of container seedlings in nursery production programs. p. 129-138. In Proc. Servicewide Conference on Planting Stock Production, Coeur d'Alene, Idaho, Sept. 16-18. USDA For. Serv. Div. Timber Manage., Washingto D. C., 211 p.

Tinus, Richard W., and Stephen E. McDonald.
1979. How to grow tree seedlings in containers in greenhouses. USDA For. Serv. Gen. Tech. Rep. RM-60, 256 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Xydias, G. K.
1981. Trends in southern forest industry plantation survival 1960-1978. In Proc. Symp. on Engineering Systems for Forest Regeneration Am. Soc. Agric. Eng. [Raleigh, N. C., Mar. 2- 1981] (in press.)

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Classification and Evaluation of Forest Sites on the Mid-Cumberland Plateau

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SUMMARY

This paper presents a comprehensive forest site classification system for the middle portion of the Cumberland Plateau in northern Alabama and central Tennessee. The system is based on physiography, geology, soils, topography, and vegetation. Twenty landtypes are described, and each landtype is evaluated in terms of productivity and desirability of selected pines and hardwoods for timber production. Also, each landtype is rated for five soil-related problems that can affect forest management operations.

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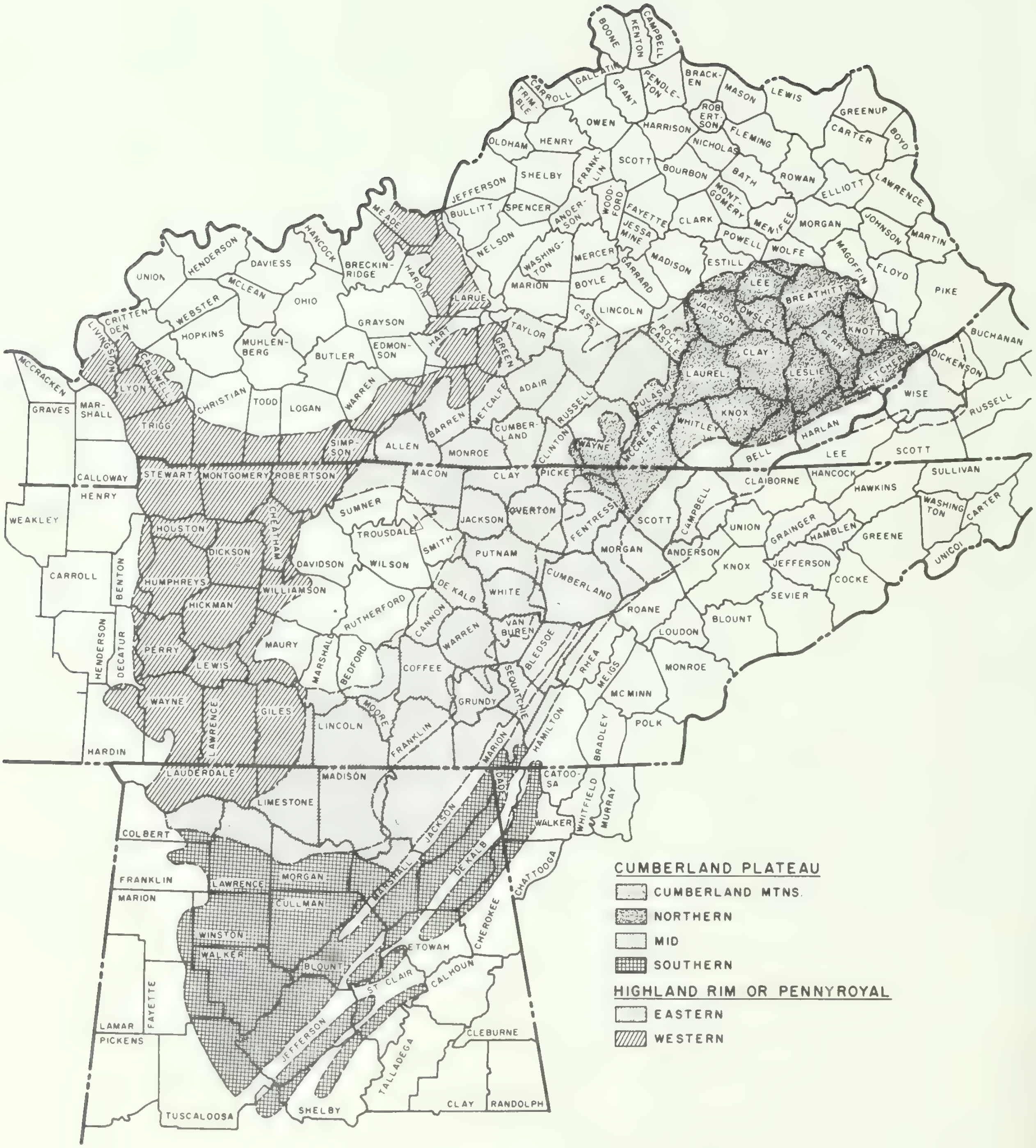

Figure 1—*Physiographic provinces and regions of the Interior Uplands.*

Classification and Evaluation of Forest Sites on the Mid-Cumberland Plateau

Glendon W. Smalley

INTRODUCTION

This report classifies and evaluates forest sites on the Mid-Cumberland Plateau (fig. 1) for the management of a number of commercially valuable tree species. It provides forest managers with a land classification system that will enable them to (1) subdivide forest land into logical segments (landtypes) each having about equal productivity, (2) rate productivity, and (3) recognize any limitations and hazards that the landtypes impose on forest management activities. Although soils information is an integral part of this system, users will not need to identify and classify soils or to make laboratory determinations. This report is oriented to timber production because timber is usually a major management objective. However, landtypes can also be the basis for the management and interpretation of other forest resources.

I have drawn freely on much published information on geology, physiography, soils, sites, and yields. In many cases, data specific to this area were not available and information was extrapolated from adjacent regions. Extrapolation was necessary with productivity data in particular. All data sources are documented so the user can gauge the accuracy and reliability of the information.

Productivity and management problem information is presented in a format that follows the outline used by the Soil Conservation Service (SCS) in the Woodland Suitability sections of county soil surveys. This similarity should facilitate the integration of information contained in county soil surveys[1] into this classification system.

This guide represents the best information and collective judgment now available. Nevertheless, it is still incomplete. I trust that forest managers will share their experience with me after applying this site classification system and alert me to shortcomings or needed revisions.

The rationale and methodology for the development of a site classification system for the Interior Uplands appeared in the proceedings of the Second Central Hardwood Forest Conference (Smalley 1978) and the Forest Soils and Site Quality Workshop (Smalley 1979a). Site classification guides for the Southern Cumberland Plateau Region and the Western Highland Rim and Pennyroyal Region have also been published (Smalley 1979b, 1980).

MID-PLATEAU REGION

The Mid-Plateau region covers about 4,450 mi^2, in all or part of 18 counties in Tennessee and 3 in Alabama. The region extends south to north from about north latitude 34°25′ to 36°30′ and east to west from about west longitude 84°35′ to 86°40′. It extends from near Oneida in Scott County, Tenn., to the Tennessee River in Marshall County, Ala., a distance of about 180 mi (fig. 2).

The Mid-Plateau consists of nearly all of the Cumberland Plateau in Tennessee plus that portion in northern Alabama lying north and west of the Tennessee River (Fenneman 1938).

The northern boundary of the Mid-Plateau is about on a line from Oneida to Jamestown in Fentress County. This line marks the northern limit of the undulating, submaturely dissected portion of the Plateau. Here the more dissected western margin of the Plateau has widened until it extends nearly to the western side of the Cumberland Mountain Region (fig. 2). The Cumberland Mountains are easily distinguished by elevation and relief because they are higher and more rugged than the adjacent Plateau. The southern boundary of the Mid-Plateau region is the Tennessee River.

The eastern edge of the region is an escarpment (Cumberland Front), which is straight to smoothly curving and only slightly notched by drainages that empty eastward into the Tennessee River. East of the Mid-Plateau is the Ridge and Valley physiographic province. In contrast, the western edge facing the Eastern Highland Rim, is a very ragged escarpment deeply incised by coves cut by tributaries of the Cumberland, Duck, and Elk Rivers.

The Mid-Plateau is cleft by the Sequatchie Valley, but this limestone valley is considered part of the Ridge and Valley physiographic province.

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[1] See Appendix for available soil surveys.

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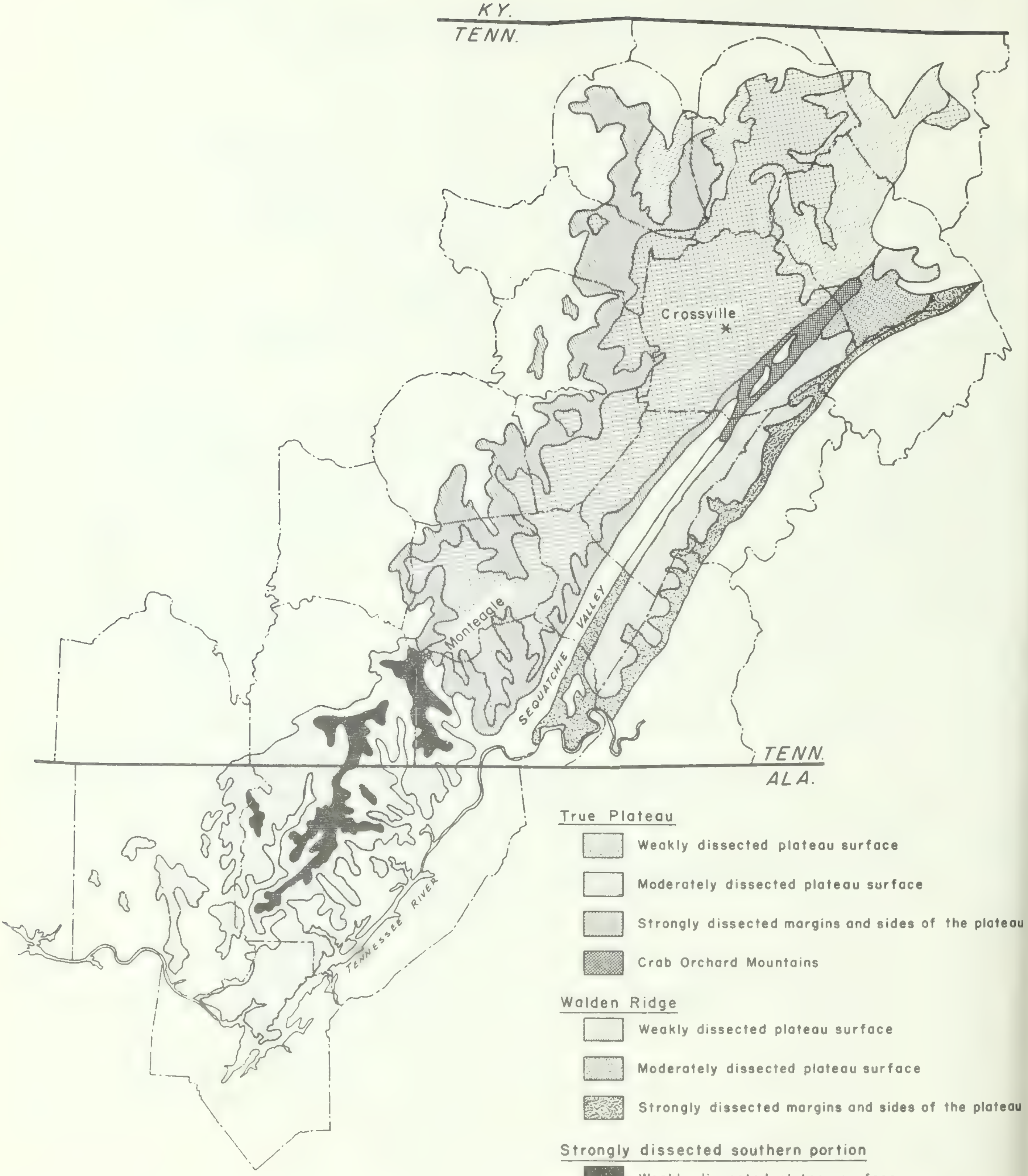
KY.
TENN.
Crossville
Monteagle
SEQUATCHIE VALLEY
TENN.
ALA.
TENNESSEE RIVER
True Plateau
Weakly dissected plateau surface
Moderately dissected plateau surface
Strongly dissected margins and sides of the plateau
Crab Orchard Mountains
Walden Ridge
Weakly dissected plateau surface
Moderately dissected plateau surface
Strongly dissected margins and sides of the plateau
Strongly dissected southern portion
Weakly dissected plateau surface
Strongly dissected margins and sides of the plateau

Figure 2—*Subregions and landtype associations of the Mid-Cumberland Plateau region and location of weather stations.*

Climate

The region has a temperature climate characterized by long, moderately hot summers, and short, mild winters. According to Thornthwaite's (1948) classification of climate, it is humid mesothermal. Daily and seasonal weather is controlled largely by alternating cold, dry continental air masses from Canada and warm, moist air from the Gulf of Mexico. During the summer, complete exchanges of air masses are few, and tropical maritime air masses persist for extended periods. Tables 1 and 2 show average monthly and annual precipitation and temperature values, average frost-free periods, and elevation above sea level for two stations in Tennessee (fig. 2).

Mean temperature for the region is about 56°F. The date of last freeze is mid April and the date of first freeze is mid to late October. The frost-free period ranges from 160 to 200 days. The temperature often falls below freezing at night in December, January, and February. The ground freezes to a depth of 2 to 6 in. several times during the average winter season and commonly remains frozen for 2 to 12 days. While air temperature does not appear to vary much across the region, local temperatures vary considerably because of elevation, aspect, and cloud cover. Midafternoon temperatures in the summer range from 5 to 7 degrees lower on the Plateau than in the adjacent limestone valleys or on the Eastern Highland Rim.

Southerly winds prevail from May to September; northerly winds from November to March. Average velocity ranges from 5 to 10 mi/h. Infrequent severe winds are usually associated with late spring and summer thundershowers.

Annual precipitation averages about 59 in. and ordinarily is fairly well distributed throughout the year, but short periods of very wet or very dry weather are common. Rainfall decreases slightly from south to north. Precipitation is greatest from December through March. Least precipitation is from August through October. Thunderstorms with high-intensity rainfall and occasionally hail occur on more than 50 days each year, mostly in the late spring and summer months. Snowfall seldom exceeds a few inches and melts in a few days. Soils are wettest from December to April and driest from July to October. Tree growth is commonly retarded because of insufficient soil moisture for periods of a few to several days up to six times each growing season.

Soil dryness during the growing season can also be shown by "frequency of drought days" data (Knetsch and Smallshaw 1958). A drought day is a day when precipitation and evapotranspiration data indicate that soil moisture content is below the wilting point. At Sewanee (6 miles southwest of Monteagle, Tenn.) drought days are most likely in August, when the probability of 10 drought days per month is 27 percent. The next highest probability of drought days is in June, July, and September when the probability of 10 drought days is 15 to 18 percent. At Crossville, drought days are most likely in July, August, and October when the probability of 10 drought days per month is 16 to 18 percent. These low probabilities indicate that precipitation on the Plateau is well-distributed throughout the growing season in most years. These data were calculated for soils having 4 inches of available moisture storage. The probability of drought will be greater on soils with less storage capacity and vice vera.

Nearly all surface streams on the Plateau stop flowing in late summer and autumn.

Geology, Topography, and Soils

The Plateau is capped by Pennsylvanian rocks, but Mississippian rocks crop out on lower slopes below the escarpment. Rocks of Cambrian-Ordovician age are exposed in the Sequatchie Valley, and Cambrian strata have been thrust to the surface along the eastern escarpment (Wilson and Stearns 1958).

Bedrock of the Plateau surface is sandstone, shale, and conglomerate belonging to the Gizzard, Crab Orchard Mountains, and Crooked Fork Groups. Age of surface rocks decreases from south to north (Swingle and others 1966).

The southern half of the Mid-Plateau consists of a thin overthrust sheet of Pennsylvanian rocks. The northern limit of this overthrust sheet is a complex series of faults that cross the Plateau from Elverton on the east to Spencer on the west. The thrust sheet is known to extend southward at least to Alabama. North of the fault complex and west of the Cumberland Mountain Region is an area undisturbed by thrust faulting.

Table 1.—*Average monthly and annual precipitation in inches for two weather stations on the Mid-Cumberland Plateau*[a]

Station and County	Years of Record	Elevation Ft.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Monteagle Grundy, TN	38	1940	6.37	6.18	6.59	5.54	4.31	4.29	5.45	4.23	3.92	3.13	4.72	6.25	60.98
Crossville Cumberland, TN	65	1810	5.62	5.51	6.08	5.08	4.16	4.48	5.09	4.09	3.98	2.75	4.38	5.60	56.82

U.S. Department of Commerce (1976).

Table 2.—*Average monthly and annual temperature in °F and length of warm period for two weather stations on the Mid-Cumberland Plateau*[a]

Station and County	Years of Record	Jan.	Feb.	Mar.	Apr.	May.	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Warm Period Days[b]
Monteagle Grundy, TN	38	38	40	47	58	66	72	75	74	69	59	47	39	57	199
Crossville Cumberland, TN	63	34	36	44	55	63	70	73	72	66	56	45	36	45	159

[a] U.S. Department of Commerce (1976).

[b] Mean period from last 32° F to first 32° F.

This geologic break would seem to be a logical division between the Northern and Mid-Plateau Regions. However, soils formed from these overthrust rocks are no different than those formed in the undisturbed area (Elder and Springer 1978). Consequently, the boundary between the Northern and Mid-Plateau Regions is defined mostly by the degree of surface dissection.

The Sequatchie Valley, which bisects the Plateau, is a subsidiary (deeper seated) break in the Cumberland Plateau overthrust system. Rocks from the southeast were pushed up and over rocks to the northwest along a break that is now the west side of the Sequatchie Valley. This overriding block was folded into an arch or anticline. The southeast flank dips gently, but the northwest flank is steep and locally even vertical. Along most of the crest of this anticline, resistant Pennsylvanian rocks were broken or finally eroded, exposing less resistant carbonate rocks into which the Sequatchie River has cut. At the head of the Valley, Pennsylvanian strata have been locally breached and erosion has cut into the underlying Mississippian carbonate rocks, forming Grassy and Crab Orchard Coves. Essentially Grassy Cove is a 3,800-acre sinkhole (Lane 1953). Northeast of these coves are the Crab Orchard Mountains, representing the unbreached northern end of the Sequatchie Valley anticline. Other lower mountains (Peavine, Hatfield, Chestnut Oak Ridge, and Cardiff Ridge) represent the remains of surficial anticlines of the Cumberland Plateau overthrust sheet (Wilson and Stearns 1958).

Topography of the Mid-Plateau ranges from gentle to rugged and complex, and slope varies from nearly level to very steep. Depressions are common on the undulating Plateau surface. Sinkholes have developed along the ragged western edge and on the deeply dissected southern portion, where the sandstone caprock is thin or absent and limestone exposed. Relief is commonly 100 to 400 ft in the interior of the Plateau, and is 1,000 ft or more at the escarpments bordering the Highland Rim and Ridge and Valley physiographic provinces.

The undulating Plateau surface averages 1,700 to 2,000 ft above sea level in Tennessee but declines southward to less than 1,500 ft in northern Alabama. Some crests of the Mid-Plateau, particularly the Crab Orchard Mountains, exceed 2,200 ft. Highest elevations are associated with the mountains at the northern end of the Sequatchie Valley. Several peaks exceed 2,600 ft; Hinch Mountain is the highest with an elevation of 3,040 ft. The floor of Grassy Cove is about 1,600 ft.

On the Mid-Plateau, upland soils have developed from a variety of sedimentary rocks. Soils derived from sandstone and conglomerate are common in the south, central, and northwest sections of the Plateau, where surface rocks are thick sandstone members of the Crab Orchard group. Soils derived from shale members of the Crooked Fork group are heavier textured than those derived from sandstone. These clayey soils are recognized in a distinctive series of landtypes and occur from northern Rhea and southeastern Cumberland Counties, Tenn. northward along the western edge of the Cumberland Mountains. Inextensive areas of shale-derived soils also occur south of highway I-24, where thick shale members of the Gizzard group are exposed (Wilson and Stearns 1958, Swingle and others 1966).

Soils vary from deep to shallow and are mostly well drained. All are acid and low in fertility. Common soils are Hartsells, Albertville, Lonewood, Ramsey, Hector, and Gilpin. Smooth areas are suited to agriculture, but forests occupy 65 percent to as much as 85 percent of Mid-Plateau counties (Hedlund and Earles 1971, 1973).

There are no extensive floodplains or terraces associated with the drainage network. Most permanent streams have cut deep V- or narrow U-shaped channels, usually rimmed with sandstone ledges. Floodplains are long and narrow. Soils are deep, moderately well drained to well drained, and moderately fertile. Common soils are Sewanee, Ealy, and Clifty.

Below the Plateau escarpment are steep, rock-strewn colluvial slopes. All are forested except for a few benches. Productivity varies greatly with aspect and slope position. Soils on upper slopes developed in colluvium from sandstone-, siltstone-, and shale-derived soils; on lower slope, soils developed in residuum from limestone. Common soils are Grimsley, Jefferson, Bouldin, and Allen.

Gradient, aspect, slope length, and soil moisture are important factors in the delineation of landtypes described later. Slope and topography affect the rate and amount of both surface runoff and subsurface movement of soil water. Soil loss by erosion increases as slope gradient and length increase. Although surface runoff is rare under forested conditions, it is an important factor during road construction, logging, and other forest management operations. Soils on steep slopes are often shallower than soils on more nearly level terrain. Deposition of sediments on gentle terrain by surface runoff is greatest below the longer and steeper slopes.

Generally, the steeper the gradient and the longer the slope, the greater the subsurface flow of soil water downslope. As a consequence, plants on lower slopes grow for longer periods without moisture stress. Subsurface flow may result in excessively wet soil with poor aeration at the base of long slopes. Lower slopes below the Plateau escarpment are an exception. Here, soil water percolates deep into the porous limestone instead of moving downslope in the soil.

Aspect affects air and soil temperatures. Soil temperatures tend to be lower on north-facing than on south-facing slopes. In deep, narrow gorges that cleft the Plateau surface, shading is an important site factor because it mollifies the usual warm microclimate of south and west slopes to one more nearly like cool north and east slopes. Because soils on north-facing slopes tend to retain moisture for longer periods during the growing season, both rate of tree growth and species composition are better on north-facing than on south-facing slopes.

In soil taxonomy, temperature regime is one of several differentiae used to group soils within a subgroup having similar physical and chemical properties (Soil Survey Staff 1975). On the Mid-Cumberland Plateau, two soil temperature classes are recognized—mesic and thermic. Mean annual temperature of mesic soils ranges from 8° to 15° C (47° to 59° F) and thermic soils from 15° to 22° C (59° to 72° F). Both classes also have a difference of 5° C (9° F) or more between mean summer and mean winter soil temperature. All temperature measurements are at a depth of 50 cm or at a lithic or paralithic contract, whichever is shallower.

Nearly all soils mapped in the Alabama portion of the Mid-Plateau are thermic. In Tennessee, mean annual soil temperature on the Plateau is less than 15° C, but both mesic and themic soils are recognized.

Vegetation

Braun (1950) assigned the Cumberland Plateau in Tennesee and northern Alabama to the Cliff Section of the Mixed Mesophytic Forest Region, although mixed oak and oak-hickory communities were dominant and nixed mesophytic communities were restricted to oves or gorges. This assignment was made on the upposition that mixed mesophytic communities would be dominant when the Plateau became maturely disected. It would have been more meaningful to classify nd map existing vegetation patterns, not those which ay develop millenia from now.

Researchers have studied vegetation of the Mid-Plateau extensively in recent years, but they have emphasized the cove communities (e.g., Caplenor 1979, Quarterman and others 1972, Schmalzer and others 1978). Compared to the coves, the pine and hardwood communities on the submaturely dissected Plateau surface have been little studied (McCarthy 1976, Smith 1977, Wade 1977).

All of these studies have sought to identify and classify existing forest communities, i.e., typical descriptive botanical studies. Some investigators have used correlation and/or multiple regression techniques to predict the importance of overstory species to soil and topographic factors. Except for the effort by the SCS to determine mean site indices of selected tree species by soil series, no attempt has been made to determine relative or absolute productivity of Plateau forest sites other than on a regional basis (Hedlund and Earles 1971, 1973).

SUBREGIONS AND LANDTYPE ASSOCIATIONS

Subregions

The Sequatchie Valley and Crab Orchard Mountains form a convenient line for subdividing the Mid-Plateau region. That part of the plateau west of the Sequatchie Valley is called by the name applied to the whole—The Cumberland Plateau—which is the typical or *True Plateau* (Subregion 1). That part of the plateau east of the Sequatchie Valley is called *Walden Ridge* (Subregion 2), named for Elijah Walden, one of the famous "Long Hunters" of the Daniel Boone era (Luther 1977). Southwest of Battle Creek on highway I-24 on a line from Kimball to Monteagle, Tenn. the plateau is so dissected it bears little resemblance to a plateau. This *Strongly Dissected Portion* is Subregion 3 (fig. 2).

1. The *True Plateau* has an undulating surface submaturely dissected by young valleys whose steepness and depth increase toward the Plateau edges. Only a few drainages such as Battle Creek and the Little Sequatchie River have breached the east-facing escarpment of the Sequatchie Valley. On the west the escarpment is cleft by many deep coves, which penetrate the Plateau for miles. These coves usually end in box canyons, where streams cascade over the sandstone escarpment. Some of the waterfalls are scenic attractions. Fall Creek Falls in Van Buren County, Tenn. is 256 ft in height—more than twice as high as Niagara Falls (Luther 1977). Sinkholes are common along the western margin, where the sandstone cap is thin or absent and limestone exposed.

For convenience the Crab Orchard Mountains and other lesser mountains associated with the Sequatchie Valley anticline and the Cumberland Plateau overthrust sheet (Wilson and Stearns 1958) are included in Subregion 1.

2. *Walden Ridge* is more dissected than the True Plateau. Nearly all surface drainage is southeastward

into the Tennessee River. The surface is dissected by young valleys whose steepness and depth increase toward the escarpment. A few streams have formed short box canyons, and everywhere streams cascade over the sandstone escarpment in scenic waterfalls. South of the Tennessee River gorge, Walden Ridge becomes Sand Mountain, which was classified as the Table Plateau Subregion in the Southern Cumberland Plateau regional guide (Smalley 1979b).

3. In the *Strongly Dissected Portion* maturely dissected, strongly sloping land predominates, and surface drainage is mostly southward to the Tennessee River. Steep, rocky coves and broad limestone valleys comprise most of the drainage network. The limestone valleys belong to the adjacent Ridge and Valley or Eastern Highland Rim physiographic regions. The small proportion of undulating land on the Plateau surface is dissected by young valleys whose steepness and depth increase toward the escarpment. Waterfalls are common throughout the subregion where streams cascade over the sandstone escarpment. Outliers are common; Monte Sano Mountain east of Huntsville, Ala. is a good example. These outliers are remnants of the Plateau that have been cut off during past erosion cycles. Some outliers have had the sandstone caprock eroded away and appear as limestone knobs and ridges projecting above the surrounding surface of the Eastern Highland Rim and Sequatchie Valley.

Landtype Associations

Each subregion was further divided into landtype associations (LTA) that correspond closely to soil associations shown on general soil maps of Alabama and Tennessee (Hajeck and others 1975; Elder and Springer 1978). Landtype associations A and C occur in all three Subregions. LTA-B occurs in Subregions 1 and 2, and LTA-D occurs only in Subregion 1 (table 3).

A. *Weakly Dissected Plateau Surface*. This LTA corresponds to soil association H11 (Hartsells-Lonewood-Ramsey-Gilpin) in Tennessee and extends south into northeastern Alabama, where it merges with soil association 12 (Hartsells-Linker-Albertville). Also included is soil association 14 (Hartsells-Wynnville-Albertville) on Gunters Mountain in Marshall County, Ala., and two areas of soil association H12 (Hartsells-Ramsey-Gilpin) near Huntsville in Scott County and Wartburg in Morgan County, Tenn.

Landtype Association-A consists mostly of broad undulating to rolling ridges flanked by gentle to moderately steep side slopes. Only the larger creeks and rivers have perennial flow. Valleys in the upper reaches of stream systems are U-shaped and may contain poorly drained flats. Further downstream, cross sections become narrow U- to V-shaped and channels are usually bounded by outcrops of sandstone.

Undulating parts of LTA-A have moderately deep to deep, well drained, loamy soils, while steeper parts have shallower soils. Soils developed mostly in residuum from sandstone and, in places, from siltstone or shale.

Smoother parts have been cleared for agriculture, particularly in the vicinity of Crossville, Tenn. and Skyline, Ala. There is considerable acreage of abandoned fields that is reverting to woodland. Fifteen landtypes are recognized: 1–15.

B. *Moderately Dissected Plateau Surface*. This LTA corresponds to soil association H22 (Ramsey-Hartsells-Grimsley-Gilpin) in Tennessee.

Landtype Association-B consists of narrow to moderately broad ridges flanked by moderately steep to steep side slopes. Stream channels are incised into the Plateau surface and cross sections are narrow U- or V-shaped and bounded by sandstone ledges. Close to the Plateau edge, stream channels are narrow and steep-sided, and end abruptly at the Plateau escarpment.

Landtype Association-B occurs in a wide band bordering the Cumberland Mountain region in Morgan and Scott Counties, Tenn. It is also associated with the Obey River in Overton and Fentress Counties, Tenn. In the latter area, LTA-B replaces LTA-C as the transition zone between the Plateau top and the Eastern Highland Rim.

The well drained, loamy, and stony soils are derived from sandstone and shale. Landtype Association-B has a higher portion of shale-derived soils than does LTA-A.

Nearly all of LTA-B is forested. Most agricultural activity is classified as family subsistence. Fifteen landtypes are recognized: 1–15.

C. *Strongly Dissected Margins and Sides of the Plateau*. This LTA corresponds to soil association H21 (Bouldin-Rock outcrop-Ramsey) in Tennessee and soil association 13 (Hartsells-Rockland, limestone-Hector) in Alabama.

Landtype Association-C represents the strongly dissected margins of the Plateau above the escarpment and steep colluvial slopes below the escarpment. This LTA occurs on both the east and west sides of the Plateau and around the Sequatchie Valley and other coves that indent the Plateau. It is the dominant LTA in Subregion 3 (Strongly Dissected Portion).

On top of the Plateau, LTA-C consists mostly of narrow ridges flanked with steep side slopes. Stream channels are V-shaped and usually bounded by sandstone ledges.

The loamy, shallow to moderately deep soils are formed mostly in residuum from sandstone and, in places, from siltstone and shale.

Below the escarpment LTA-C consists of steep colluvial slopes with numerous rock ledges, boulders, and benches. These slopes extend from the sandstone escarpment down to the adjacent limestone valleys. Escarpment slopes may be exposed or sheltered in the deep gorges that penetrate the western side of the Mid-Plateau region.

Table 3.—*Subregions and landtype associations of the Mid-Cumberland Plateau region*

Subregion	Landtype association
1. True Plateau	A. Weakly dissected plateau surface B. Moderately dissected plateau surface C. Strongly dissected margins and sides of the plateau D. Crab Orchard Mountains
2. Walden Ridge	A. Weakly dissected plateau surface B. Moderately dissected plateau surface C. Strongly dissected margins and sides of the plateau
3. Strongly dissected portion	A. Weakly dissected plateau surface C. Strongly dissected margins and sides of the plateau

Soils on upper slopes are shallow to deep, loamy, well drained, and contain varying amounts of coarse fragments. The surface is strewn with sandstone rocks and boulders. These soils developed in colluvium and alluvium from soils on the Plateau top. On lower slopes the silty and clayey, flaggy soils are well drained to somewhat poorly drained and derived from clayey residuum from limestone. Limestone rockland is extensive.

Nearly all of LTA-C is forested. Some benches have been cleared, but most have reverted to woodland. Thirteen landtypes are recognized: 2–7 and 14–20.

D. *Crab Orchard Mountains.* This LTA includes the Crab Orchard Mountains and the peaks surrounding Grassy and Crab Orchard coves. It corresponds to the northern part of soil association H21 (Bouldin-Rock-outcrop-Ramsey) and a small portion of H22 (Ramsey-Hartsells-Grimsley-Gilpin).

Landtype Association-D consists of narrow to moderately broad mountain ridges flanked by moderately steep to very steep side slopes. Northwest-facing slopes tend to be steeper than southeast-facing slopes. Local relief is nearly 1,000 ft in places. These uplands are dissected by a moderately well developed dendritic drainage system. However, floodplains are narrow or nonexistent because of steep topography.

Loamy and clayey soils are well drained to somewhat excessively drained and derived from sandstone or shale residuum. Soils on steep mountain slopes developed in colluvium from alternating strata of sandstone and shale. Shaly talus slopes are common. Eight landtypes are recognized: 2–7 and 14–15.

LANDTYPES

I have divided each landtype association into landtypes, which are the smallest unit of the landscape recognized in this classiciation system. Wertz and Arnold (1975) describe landtypes as visually identifiable areas each being reasonably uniform in soils and productivity and resulting from similar climatic and geological processes.

The Mid-Cumberland Plateau has 20 landtypes distributed among three subregions and four LTA's (table). Some are common to all four associations, while others are characteristic of only one LTA. Figures 3 to 5 depict how these landtypes occur on the landscape in each of the LTA's.

Letters in the upper right-hand corner of each landtype description identify the LTA's in which each landtype occurs.

Aspect distinguishes some landtypes and is recorded as either north or south. North aspects include all azimuths from 315° (northwest) to 135° (southeast). The remainder of the azimuth circle represents south aspects.

Each landtype is described in terms of nine elements. The **Geographic Setting** provides an overall description of the landtype, specifying both where it occurs on the landscape and its relation to other landtypes. Slope was classified in accordance with SCS standards (Soil Survey Staff 1951).

Slope Classes and Correspnding Percent of Slope

Slope percent	Class
0–2	Level or nearly level
2–6	Gently sloping
6–10	Sloping
10–15	Strongly sloping
15–25	Moderately steep
25–45	Steep
45 +	Very steep

The most prevalent soil series are listed under **Dominant Soils.** These series names reflect the most recent designations in soil classification and link this site classification system with county soil surveys published by the SCS. Users who wish more detailed information can refer to soil series descriptions issued by the SCS.

The kind of **Bedrock** or **Soil Parent Material** and **Depth to Bedrock** are listed next. **Soil Texture** is described in terms of the 12 conventional classes, which are based on percentages of sand, silt, and clay-size particles (Soil Survey Staff 1951).

The conventional seven **Soil Drainage** classes are: *very poorly drained, poorly drained, somewhat poorly drained, moderately well drained, well drained, somewhat excessively drained,* and *excessively drained* (Soil Survey Staff 1951). **Relative Soil Water Supply** of each landtype is rated in five classes: *very low, low, medium, high,* and *very high.* This qualitative rating is

Table 4.—*Summary of landtypes and their occurrence by subregion and landtype associations*

Landtype number and name of subregion	Landtype association[a]
True Plateau	
1. Broad undulating sandstone uplands	A,B
2. Broad sandstone ridges—north aspect	A,B,C,D
3. Broad sandstone ridges—south aspect	A,B,C,D
4. Narrow sandstone ridges and convex upper slopes	A,B,C,D
5. North sandstone slopes	A,B,C,D
6. South sandstone slopes	A,B,C,D
7. Sandstone outcrops and shallow soils	A,B,C,D
8. Broad shale ridges—north aspect	A,B
9. Broad shale ridges—south aspect	A,B
10. Upper shale slopes—north aspect	A,B
11. Upper shale slopes—south aspect	A,B
12. Lower shale slopes—north aspect	A,B
13. Lower shale slopes—south aspect	A,B
14. Footslopes, terraces, and streambottoms with good drainage	A,B,C,D
15. Terrace, streambottoms, and depressions with poor drainage	A,B,C,D
16. Plateau escarpment and upper sandstone slopes and benches—north aspect	C
17. Plateau escarpment and upper sandstone slopes and benches—south aspect	C
18. Lower limestone slopes, benches, and spur ridges—north aspect	C
19. Lower limestone slopes, benches, and spur ridges—south aspect	C
20. Limestone outcrops and shallow soils	C
Walden Ridge	
1. Broad undulating sandstone uplands	A,B
2. Broad sandstone ridges—north aspect	A,B,C
3. Broad sandstone ridges—south aspect	A,B,C
4. Narrow sandstone ridges and convex upper slopes	A,B,C
5. North sandstone slopes	A,B,C
6. South sandstone slopes	A,B,C
7. Sandstone outcrops and shallow soils	A,B,C
8. Broad shale ridges—north aspect	A,B
9. Broad shale ridges—south aspect	A,B
10. Upper shale slopes—north aspect	A,B
11. Upper shale slopes—south aspect	A,B
12. Lower shale slopes—north aspect	A,B
13. Lower shale slopes—south aspect	A,B
14. Footslopes, terraces, and streambottoms with good drainage	A,B,C
15. Terraces, streambottoms and depressions with poor drainage	A,B,C
16. Plateau escarpment and upper sandstone slopes and benches—north aspect	C
17. Plateau escarpment and upper sandstone slopes and benches—south aspect	C
18. Lower limestone slopes, benches, and spur ridges—north aspect	C
19. Lower limestone slopes, benches, and spur ridges—south aspect	C
20. Limestone outcrops and shallow soils	C
Strongly dissected portion	
1. Broad undulating sandstone uplands	A
2. Broad sandstone ridges—north aspect	A,C
3. Broad sandstone ridges—south aspect	A,C
4. Narrow sandstone ridges and convex upper slopes	A,C
5. North sandstone slopes	A,C
6. South sandstone slopes	A,C
7. Sandstone outcrops and shallow soils	A,C
14. Footslopes, terraces, and streambottoms with good drainage	A,C
15. Terraces, streambottoms and depressions with poor drainage	A,C
16. Plateau escarpment and upper sandstone slopes and benches—north aspect	C
17. Plateau escarpment and upper sandstone slopes and benches—south aspect	C
18. Lower limestone slopes, benches, and spur ridges—north aspect	C
19. Lower limestone slopes, benches, and spur ridges—south aspect	C
20. Limestone outcrops and shallow soils	C

[a] See table 3.

based on the available water-holding capacity of the dominant soils (a function of soil texture and thickness), but allowances are made for the influence of soil drainage, topographic position, and aspect.

Soil fertility is described as *very low, low, moderately low, moderate, moderately high, high,* or *very high.* Because soils of the Mid-Cumberland Plateau are fairly acid and derived from rocks with few weatherable minerals, the most fertile soils in the region are rated only moderate (Francis and Loftus 1977).

The most common woody species in the overstory are listed under **Vegetation** in approximate order of abundance. Important understory species are listed also, including some distinctive herbaceous groups. Although not listed, reproduction of overstory species is usually present in the understory. Loblolly pine is native only in northern Alabama and southern Tennessee but has been planted north of its range on converted sites and abandoned fields. Species nomenclature follows Little (1979) and Fernald (1950).

FOREST MANAGEMENT INTERPRETATIONS

Each landtype is evaluated in terms of productivity for selected species of trees and species desirability for timber production. Also, each landtype is rated for five soil-related problems that may affect forest management operations.

Productivity

Productivity of commercially valuable species is expressed as site index and as average annual growth in cubic feet per acre. Site index is the total height attained by dominant and codominant trees at some specified age.

For all naturally occuring species, site indices are the means of values from soil survey interpretations for dominant soils in each landtype. Interpretations are issued by the SCS as part of each soil series description. SCS personnel obtained height and age measurements in well-stocked, even-aged, essentially unmanaged stands that had not been damaged excessively by fire, insects, disease, or grazing. These stands were located on soils representing, as nearly as possible, the modal concept of each soil series. SCS personnel then used published site index curves (Beck 1962; Broadfoot 1960, 1963; Broadfoot and Krinard 1959; Curtis and Post 1962; Defler 1937; Doolittle and Vimmerstedt 1960; Nelson and others 1961; Schnur 1937; Tennessee Valley Authority 1948[2]; and U.S. Forest Service 1929) to convert height and age data to site indices. Curves for all species are based on age 50 years. Sometimes when site indices were available for one species, estimates for other species were made by using Doolittle's (1958) site index comparisons. When necessary, I adjusted these SCS site index values for aspect and slope position based on experience and soil-site research (Carmean 1975).

Site indices, base age 25 years from seed, are given for loblolly and shortleaf pines in plantations established on abandoned fields (Smalley and Bower 1971) when data for specific landtypes were available. Also site indices, base age 25 years from seed, are given for eastern white pine plantations established on abandoned fields (Vimmerstedt 1962). These values were calculated by assuming that site index, base age 50 years, of plantations would be equal to site index of natural stands reported by the SCS. These base age 50 site indices were converted to base age 25 following Vimmerstedt's (1962, p. 5) instructions.

In a few cases when no values were available, site indices (base age 50 years) of important species were estimated. Where they occur in tables 5 to 24, these estimated values are enclosed in parentheses.

Average annual growth expressed in cubic feet per acre was calculated from available yield tables (Doolittle 1956, McCarthy 1933, Nelson and others 1961, Schnur 1937, U.S. Forest Service 1929, and Winters and Osborne 1935). The yield tables represent either normal or fully stocked conditions. Annual growth rates for all naturally occurring species or forest types were averaged over 50 years.

Average annual growth rates for loblolly and shortleaf pine plantations were derived from Smalley and Bailey's (1974a, 1974b) variable-density yield tables, and a planting density of 1,000 seedlings per acre was assumed. Average growth was based on 40 years, the oldest age reported in the yield tables. Average annual growth rates for eastern white pine plantations were derived from Vimmerstedt's (1962) variable-density yield tables, and a planting density of 1,037 seedlings per acre (6 × 7 feet spacing) was assumed. Average growth was based on 35 years, the oldest age reported in the yield tables.

Though our productivity data are the best available, all site curves and yield tables except those for plantation-grown loblolly and shortleaf pine were developed either for geographic areas larger than but including the Mid-Cumberland Plateau or for areas other than the Mid-Cumberland Plateau.

Yields were not expressed in a common merchantability standard, so care should be exercised in comparing average annual yields of species both within and between landtypes. Footnotes to tables 5 to 24 specify merchantability standards used.

Management Problems

Plant Competition rates the invasion of unwanted plants after openings are made in the canopy. Plant

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Site index curves for eastern redcedar based on data from 271 plots hroughout the Tennessee River Valley

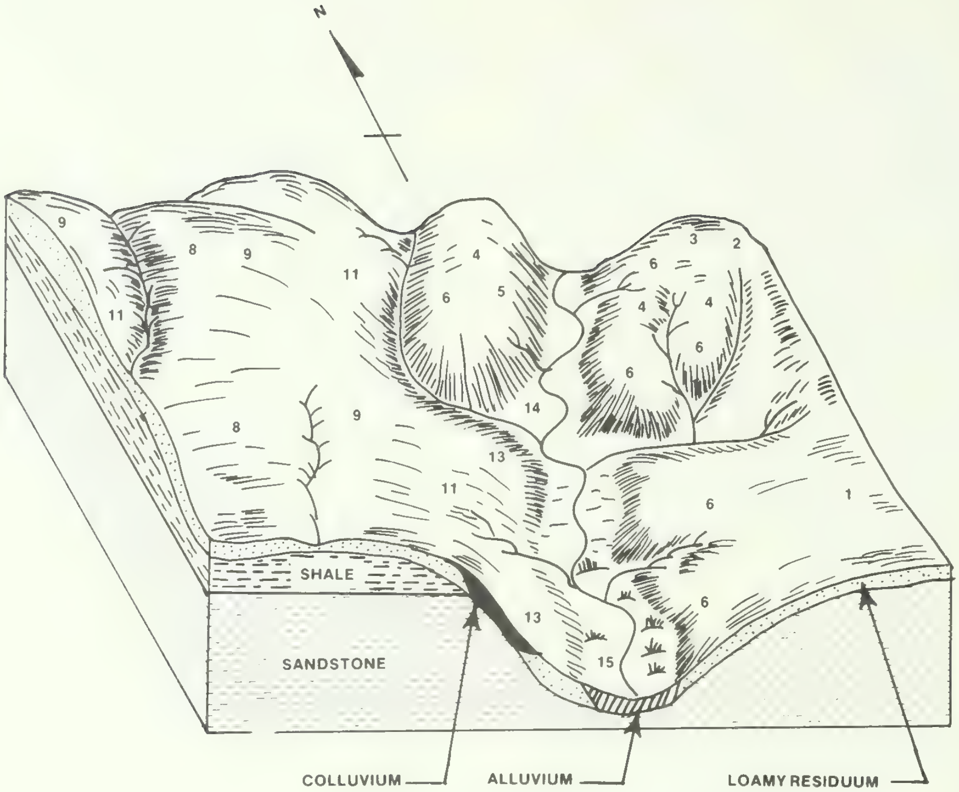

Figure 3—*Landtypes characteristic of Landtype Associations A (weakly dissected plateau surface) and B (moderately dissected plateau surface) in all subregions with soils formed from sandstone (right) and shale (left).*

LEGEND

1. Broad undulating sandstone uplands.
2. Broad sandstone ridges—north aspect.
3. Broad sandstone ridges—south aspect.
4. Narrow sandstone ridges and convex upper slopes.
5. North sandstone slopes.
6. South sandstone slopes.
8. Broad shale ridges—north aspect.
9. Broad shale ridges—south aspect.
11. Upper shale slopes—south aspect.
13. Lower shale slopes—south aspect.
14. Footslopes, terraces, and streambottoms with good drainage.
15. Terraces, streambottoms, and depressions with poor drainage.

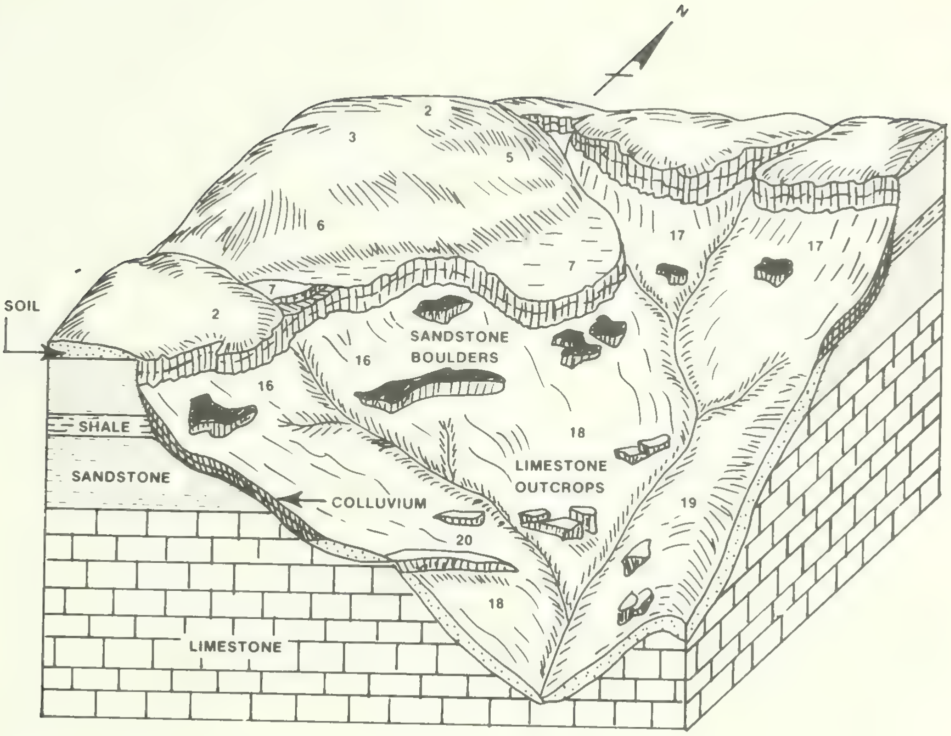

Figure 4.—*Landtypes characteristic of Landtype Association C (strongly dissected margins and sides of the plateau) in all subregions.*

LEGEND

2. Broad sandstone ridges—north aspect.
3. Broad sandstone ridges—south aspect.
5. North sandstone slopes.
6. South sandstone slopes.
7. Sandstone outcrops and shallow soils.
16. Plateau escarpment and upper sandstone slopes and benches—north aspect.
17. Plateau escarpment and upper sandstone slopes and benches—south aspect.
18. Lower limestone slopes, benches, and spur ridges—north aspect.
19. Lower limestone slopes, benches, and spur ridges—south aspect.
20. Limestone outcrops and shallow soils.

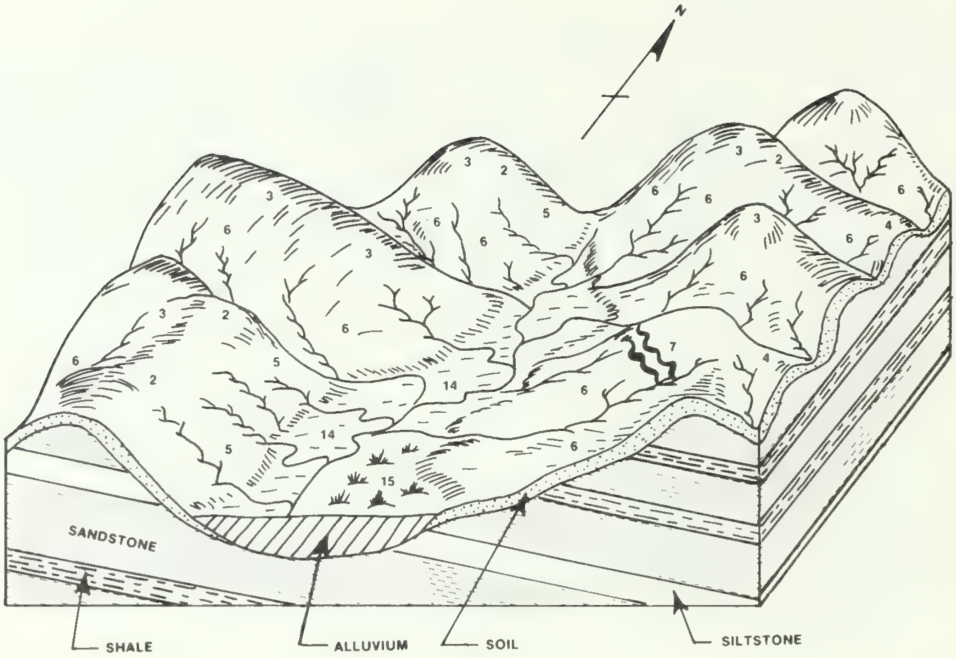

Figure 5.—*Landtypes characteristic of Landtype Association D (Crab Orchard Mountains) in Subregion 1 (True Plateau).*

LEGEND

2. Broad sandstone ridges—north aspect.
3. Broad sandstone ridges—south aspect.
4. Narrow sandstone ridges and convex upper slopes.
5. North sandstone slopes.
6. South sandstone slopes.
7. Sandstone outcrops and shallow soils.
14. Footslopes, terraces, and streambottoms with good drainage.
15. Terraces, streambottoms, and depressions with poor drainage.

competition is *slight* if unwanted plants do not prevent adequate natural regeneration, interfere with early growth, or restrict normal development of planted or seeded seedlings. Competition is *moderate* if unwanted plants delay establishment and hinder the growth of regenerated seedlings or if they retard the eventual development of a fully stocked stand. Competition is *severe* if unwanted plants prevent adequate restocking without extensive site preparation or special maintenance practices. Competition ratings in tables 5 to 24 represent regional averages, and competition on a given landtype may vary as a result of past land use.

Seedling Mortality is the loss of artificially established tree seedlings as influenced by soils and topographic conditions, assuming that planting is done properly and plant competition is insignificant. Rating is *slight* if expected mortality is 0 to 25 percent, *moderate* if expected mortality is 26 to 50 percent, and *severe* if mortality is more than 50 percent. If the rating is moderate or severe, special preparation of the seedbed and special planting techniques are often necessary to insure a fully stocked stand.

Equipment Limitations are restrictions on the use of conventional wheeled or tracked equipment. Soil and topographic characteristics (e.g., slope, drainage, texture, and rockiness) influence equipment limitations, sometimes necessitating the use of different kinds of equipment and methods of operation, or restricting the season when equipment is used. Generally, limitation is *slight* if slope is 20 percent or less and farm machinery can operate efficiently during all seasons. The rating is *moderate* if slope is 20 to 30 prcent, limits the use of ordinary farm machinery, and requires track-type equipment; or if soil wetness prevents the use of logging vehicles for 2 to 6 months a year. The rating is *severe* if slope exceeds 30 percent, making track-type equipment inadequate and requiring power vehicles and other special equipment; or if wetness prevents use of vehicles for 6 months or more a year.

Erosion Hazard is the degree of potential soil erosion that can occur during and after forest management operations that expose soil along roads, skid trails, fire lanes, and landing areas. The ratings assume that the forest is well managed and protected from fire and grazing. Soil and topographic characteristics considered in rating hazard of erosion include slope, infiltration, permeability, water holding capacity, and resistance to detachment of soil particles by rainfall and runoff. *Slight* indicates that no special measures are needed, *moderate* indicates that some attention needs to be given to erosion control, and *severe* indicates that intensive erosion-control measures are needed.

Windthrow Hazard measures how soils affect root development and how firmly soils hold trees. The hazard is *slight* if rooting depth is more than 20 inches and trees withstand most winds, *moderate* if effective rooting depth is 10 to 20 inches and some trees are blown down during excessive soil wetness and strong winds, and *severe* if effective rooting depth is 10 inches or less and trees will not stand alone in strong winds.

Species Desirability

Three categories are used for rating **Species Desirability** of species that commonly occur on each landtype. *Most Desirable* species are those that have potential for fast growth, high value, or both. *Acceptable* species are those with moderate growth rate or value. *Least Desirable* species are those with slow growth, poor quality, or both. These ratings represent the average situation for the region. The presence or absence of local markets could result in a species being assigned to another category.

USING THE SYSTEM

This guide will allow professional foresters, forest landowners, landuse specialists, forest researchers, and other resource professionals to make onsite determinations of site productivity and will provide a site-dependent framework for forest management planning and forest research.

To make onsite determinations of productivity on a particular tract of land, the user must first determine the subregion and LTA in which the particular tract of land occurs by referring to tables 3 and fig 2. Landtypes common to each LTA are shown in table 4. Landtype descriptions and landscape drawings (figs. 3 to 5) will enable the user to identify specific landtypes. Information about productivity, severity of management problems, and species desirability are shown on pages facing the landtype descriptions (tables 5 to 24).

This site classification system provides a sound biological basis for forest management planning because it recognizes inherent site differences and soil-related hazards. When the system is adopted, landtypes become the basic unit of management. Continuous Forest Inventory or other forest inventory systems can easily be incorporated into this site classification system to obtain information on acreage, stocking, composition, and growth of forests by landtypes. Once productivity data are available for landtypes on a specific tract, they should be substituted for the regional values in the appropriate tables.

Users should be aware that productivity will vary within a landtype. This variation should be handled as a sampling problem dependent on the desired precision of the productivity information. To sample some landtypes adequately, users with existing inventory systems may be required to install new plots or points. Excessive variation in productivity within a landtype may indicate the need to divide that landtype into more homogenous units.

A logical vehicle to transfer this site classification system into a valuable forest management tool is a landtype map (fig. 6), which can be used in all phases of management from day-to-day activities to long-range planning. The number and scale of maps will depend on size of ownership and how intensively one wishes to manage. Landtypes can be mapped at scales of 1:10,000 to 1:60,000 and at these scales, areas as small as 2 acres can be recognized on the larger scale maps. Smoothness of the terrain will determine maximum size. So the U.S. Geological Survey 7½-minute quadrangle sheets (1:24,000) make excellent base maps on which to delineate landtypes. Black and white or color aerial photos, particularly stereo pairs, can also serve as base maps. A reasonable amount of ground checking should be part of the mapping process. Owners or managers of large tracts should explore the advantages of computer-generated mapping of landtypes and other physical and biological features of the landscape (Beeman 1978). A photo-interpretation key for forest cover is available for Subregion 3—Strongly Dissected Portion (Johnson and Sellman 1979).

For forest researchers, this site classification system provides a basis for stratifying study areas. The system also aids in identifying and isolating problems that need to be researched. For example, it became apparent in compiling site index and growth information that little mensuration data specific to the region are available. Finally, the system provides researchers with a vehicle for quick transfer of research results to the practitioner. Study results can be reported on the basis of their applicability to specific landtypes.

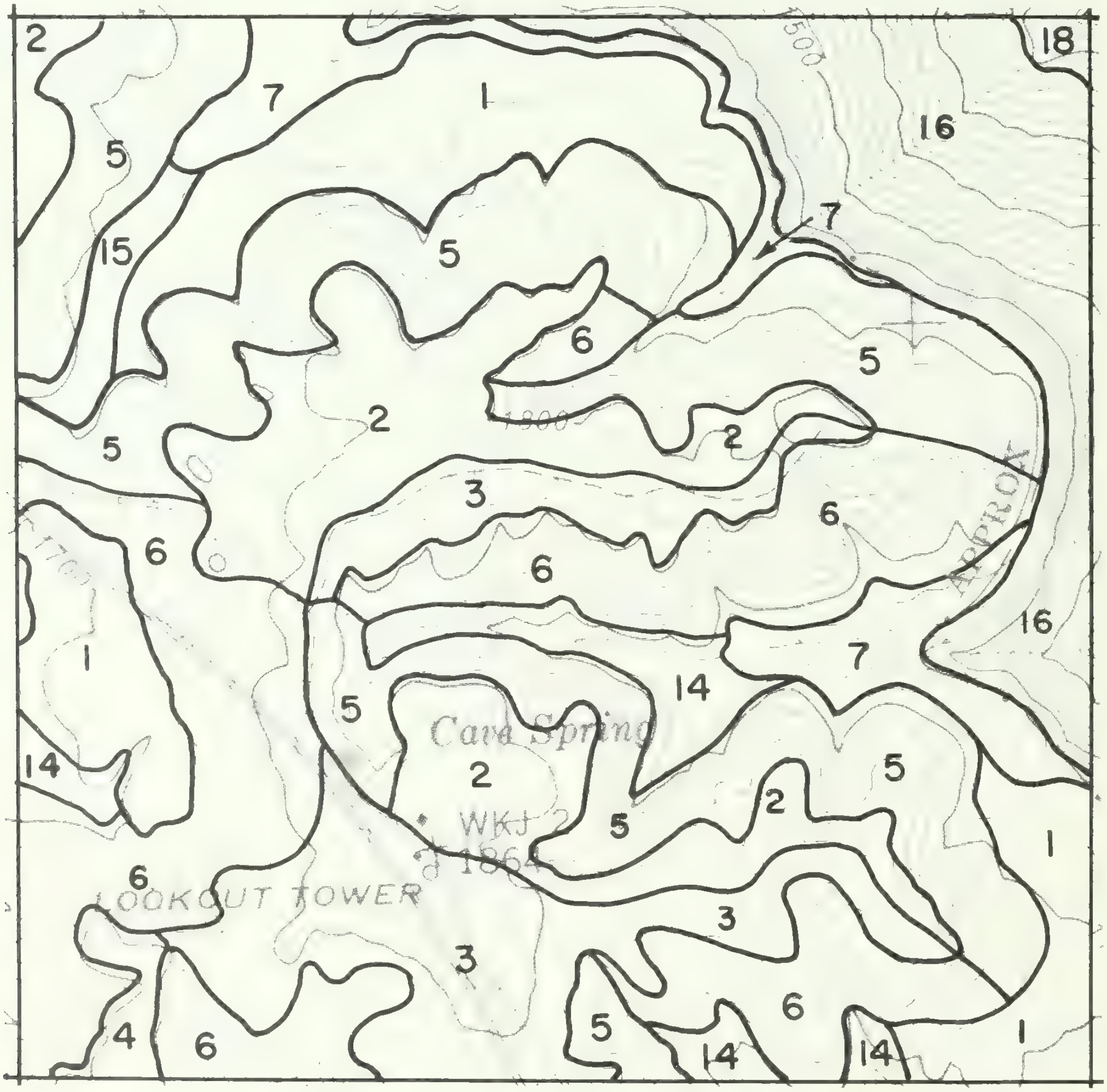

Figure 6.—*A sample landtype map showing Landtype Associations A (weakly dissected plateau surface) and C (strongly dissected margins and sides of the plateau) in Subregion 3. Map covers a tract of about 700 acres on the Franklin-Marion State Forest located in the northwest quarter of the Orme Quadrangle, Marion County, Tenn. Scale is 1:12,000. See table 4 for names of landtypes.*

Description of Landtype 1: Broad Undulating Sandstone Uplands

Geographic setting—Moderately deep to deep, loamy and clayey soils on level to sloping broad ridges that typically occupy the smoother and higher parts of the landscape in all subregions but more frequently in Subregion 1. Slope does not exceed 10 percent, but the area with slope greater than 6 percent is small and aspect is not a dominant factor. These uplands may range up to 0.5 mile in width. Soils developed in loamy residuum from sandstone or from interbedded sandstone and shale. In some places a 2- to 3-foot silty mantle (presumably loess) occurs over the residuum. This landtype grades into steeper broad ridges (Landtypes 2 and 3) or into midslopes (Landtypes 5 and 6).

Dominant soils—Hartsells, Linker, Lonewood, Crossville, Lily, and Clarkrange are more common in Subregions 1 and 2, while Albertville, Enders, Nauvoo, and Wynnville are more common in Subregion 3. Volume of sandstone, and in places shale, fragments is 35 percent or less in the solum, but deeper horizons may contain more. Clarkrange and Wynnville soils have fragipans at depths of 18 to 28 inches.

Bedrock—Sandstone and conglomerate with thin strata of shale and siltstone in places.

Depth to bedrock—20 to 90 inches.

Texture—Loam, fine sandy loam, and silt loam; sometimes gravelly, stony, or flaggy.

Soil drainage—Well drained except Clarkrange and Wynnville soils are moderately well drained.

Relative soil water supply—Medium.

Soil fertility—Moderately low.

Vegetation—White oak, scarlet oak, southern red oak, chestnut oak, hickories, black oak, blackgum, red maple, shortleaf pine, Virginia pine, and loblolly pine; occasional yellow-poplar, eastern white pine, post oak, sweetgum, black locust, black cherry, and eastern redcedar. Dogwood, sassafras, sourwood, serviceberry, persimmon, sumac, hawthorns, viburnums, vacciniums, azaleas, American holly, and smilax are common understory species.

Table 5.—*Forest management interpretations for Landtype 1: Broad Undulating Sandstone Uplands. Footnotes appear on page 56.*

PRODUCTIVITY

Species	Site index Natural Stands[1]	Site index Old-field Plantations[2]	Average annual growth cubic feet per acre Natural Stands[3]	Average annual growth cubic feet per acre Old-field Plantations[4]
E. white pine	75	52	126	145
Shortleaf pine	65	45	113	102
Loblolly pine	75	50	114	117
Virginia pine	70		92	
E. redcedar	30			
Upland oaks	60		43	
Yellow-poplar	85		80	

MANAGEMENT PROBLEMS

Plant Competition	Seedling Mortality	Equipment Limitations	Erosion Hazard	Windthrow Hazard
Moderate	Slight	Slight	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
E. white pine	Hickories	E. redcedar
Shortleaf pine	White oak	Post oak
Loblolly pine	Chestnut oak	Sassafras
Virginia pine	Black oak	Serviceberry
Yellow-poplar	S. red oak	Black locust
	Scarlet oak	American holly
	Sweetgum	Red maple
	Black cherry	Blackgum
		Dogwood
		Sourwood
		Persimmon

Description of Landtype 2:
Broad Sandstone Ridges—North Aspect

Geographic setting—Moderately deep to deep, loamy soils on nearly level to steep north-facing portions of broad ridgetops and adjoining convex upper slopes in all subregions. This landtype extends from the ridge crest down to where the slope becomes linear or nearly so. At this point gradient usually increases noticeably. Slope ranges from 2 to 35 percent and is dominantly greater than 6 percent. Soils developed in loamy residuum from sandstone or from interbedded sandstone and shale. In some places a 2- to 3-foot silty mantle (presumably loess) occurs over the residuum. Rock fragments occur on the surface in places. This landtype may occur below broad undulating uplands (Landtype 1) while north midslopes (Landtype 5) occur below it. This landtype may lie adjacent to Landtypes 14 and 15 in the heads of hollows.

Dominant soils—Hartsells, Linker, Lonewood, Crossville, and Lily are more common in Subregions 1 and 2, while Albertville, Enders and Nauvoo are common in Subregion 3.

Bedrock—Sandstone and conglomerate with thin strata of shale and siltstone in places.

Depth to bedrock—20 to 72 inches.

Texture—Loam, fine sandy loam, and silt loam; sometimes gravelly, stony, or flaggy. Volume of sandstone, and in places, shale fragments in the solum is 35 percent or less, but deeper horizons may contain more.

Soil drainage—Well drained.

Relative soil water supply—Medium.

Soil fertility—Moderately low.

Vegetation—White oak, scarlet oak, southern red oak, chestnut oak, hickories, black oak, blackgum, red maple, shortleaf pine, Virginia pine, loblolly pine, and eastern white pine; occasional yellow-poplar, northern red oak, black cherry, black locust, post oak, white ash, and eastern redcedar. Dogwood, sassafras, serviceberry, sourwood, persimmon, sumac, viburnums, vacciniums, azaleas, smilax, and American holly are common understory species.

Table 6.—*Forest management interpretations for Landtype 2: Broad Sandstone Ridges—North Aspect. Footnotes appear on page 56.*

PRODUCTIVITY

Species	Site index: Natural Stands[1]	Site index: Old-field Plantations[2]	Average annual growth cubic feet per acre: Natural Stands[3]	Average annual growth cubic feet per acre: Old-field Plantations[4]
E. white pine	75	52	126	145
Shortleaf pine	65	45	113	102
Loblolly pine	70	55	104	133
Virginia pine	70		92	
E. redcedar	40			
Upland oaks	65		48	
Yellow-poplar	80		71	

MANAGEMENT PROBLEMS

Plant Competition	Seedling Mortality	Equipment Limitations	Erosion Hazard	Windthrow Hazard
Moderate	Slight	Slight to moderate	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
E. white pine	Hickories	E. redcedar
Shortleaf pine	White oak	Sassafras
Loblolly pine	Post oak	Serviceberry
Virginia pine	Chestnut oak	Black locust
Yellow-poplar	N. red oak	American holly
	Black oak	Red maple
	S. red oak	Blackgum
	Scarlet oak	Dogwood
	Black cherry	Sourwood
	White ash	Persimmon

Description of Landtype 3: Broad Sandstone Ridges— South Aspect

Geographic setting—Moderately deep to deep, loamy soils on nearly level to steep south-facing portions of broad ridgetops and adjoining convex upper slopes in all subregions. This landtype extends from the ridge crest down to where the slope becomes linear or nearly so. At this point gradient usually increases noticeably. Slope ranges from 2 to 35 percent and is dominantly greater than 6 percent. Soils developed in loamy residuum from sandstone or from interbedded sandstone and shale. In some places a 2- to 3-foot silty mantle (presumably loess) occurs over the residuum. Rock fragments occur on the surface in places. South-facing ridges tend to be somewhat steeper and have shallower soils with a higher rock content than north-facing ridges. This landtype may occur below broad undulating uplands (Landtype 1) while south midslopes (Landtype 6) occur below it. This landtype may lie adjacent to Landtypes 14 and 15 in the heads of hollows.

Dominant soils—Hartsells, Linker, Lonewood, Crossville, and Lily are more common in Subregions 1 and 2, while Albertville, Enders, and Nauvoo are more common in Subregion 3.

Bedrock—Sandstone and conglomerate with thin strata of shale and siltstone in places.

Depth to bedrock—20 to 72 inches.

Texture—Loam, fine sandy loam, and silt loam; sometimes gravelly, stony, or flaggy. Volume of sandstone, and in places, shale fragments in the solum is 35 percent or less, but deeper horizons may contain more.

Soil drainage—Well drained.

Relative soil water supply—Medium.

Soil fertility—Moderately low.

Vegetation—White oak, scarlet oak, chestnut oak, southern red oak, hickories, black oak, post oak, blackgum, red maple, Virginia pine, shortleaf pine, and loblolly pine; occasional black locust, eastern redcedar, eastern white pine, and yellow-poplar. Dogwood, sassafrass, sourwood, persimmon, vacciniums, sumac, viburnums, serviceberry, and smilax are common understory species.

Table 7.—*Forest management interpretations for Landtype 3: Broad Sandstone Ridges—South Aspect. Footnotes appear on page 56.*

PRODUCTIVITY

Species	Site index		Average annual growth cubic feet per acre	
	Natural Stands[1]	Old-field Plantations[2]	Natural Stands[3]	Old-field Plantations[4]
Shortleaf pine	60	45	102	102
Loblolly pine	65	55	95	133
Virginia pine	65	—	70	
E. redcedar	35			
Upland oaks	60		43	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Slight to moderate	Slight to moderate	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
E. white pine	Hickories	E. redcedar
Shortleaf pine	White oak	Post oak
Loblolly pine	Chestnut oak	Sassafras
Virginia pine	Black oak	Serviceberry
Yellow-poplar	S. red oak	Black locust
	Scarlet oak	Red maple
		Blackgum
		Dogwood
		Sourwood
		Persimmon

Description of Landtype 4: Narrow Sandstone Ridges and Convex Upper Slopes

Geographic setting—Shallow to moderately deep, loamy soils on gently sloping to steep, winding narrow ridgetops and adjoining convex upper slopes in all subregions. Below this landtype are midslopes (Landtypes 5 and 6). Landtype 4 is more common in LTA-C (strongly dissected margins and sides of the plateau) and LTA-D (Crab Orchard Mountains). Slope ranges from 0 to 40 percent. Typically this landtype is no wider than 250 feet. Rock fragments, mostly sandstone and conglomerate, are common on the surface.

Dominant soils—Hector, Mountainburg, Ramsey, Hartsells, Alticrest, Lily, and Muskingum.

Bedrock—Predominantly sandstone and conglomerate with thin strata of siltstone and shale in places.

Depth to bedrock—40 inches or less.

Texture—Sandy loam, fine sandy loam, and loam; occasionally silt loam. Often gravelly, stony, or channery. Coarse fragment content of most soils does not exceed 35 percent in the solum, except Mountainburg and Muskingum soils, which may have as much as 60 percent. Coarse fragment content usually increases with depth.

Soil drainage—Well drained to somewhat excessively drained.

Relative soil water supply—Low.

Soil fertility—Low.

Vegetation—White oak, chestnut oak, scarlet oak, southern red oak, post oak, black oak, Virginia pine, shortleaf pine, blackgum, blackjack oak, and hickories; occasional loblolly pine, eastern white pine, black locust, yellow-poplar, and eastern redcedar. Sassafras, sourwood, dogwood, vacciniums, sumac, persimmon, and buckthorn are common understory species.

Table 8.—*Forest management interpretations for Landtype 4: Narrow Sandstone Ridges and Convex Upper Slopes. Footnotes appear on page 56.*

PRODUCTIVITY

Species	Site index		Average annual growth cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
E. white pine	70	49	115	126
Shortleaf pine	60	(40)	102	84
Loblolly pine	70	(50)	104	117
Virginia pine	65		70	
E. redcedar	30			
Upland oaks	65		48	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight to moderate	Moderate to severe	Moderate to severe	Slight to severe	Moderate to severe

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
E. white pine	Loblolly pine	E. redcedar
Shortleaf pine	Hickories	Blackjack oak
Virginia pine	Post oak	Sassafras
White oak	Chestnut oak	Black locust
Black oak	Scarlet oak	Blackgum
S. red oak	Yellow-poplar	Dogwood
		Sourwood
		Persimmon

Description of Landtype 5:
North Sandstone Slopes

Geographic setting—Shallow to moderately deep, loamy and clayey soils with a wide range of coarse fragments on sloping to very steep north-facing linear to concave midslopes in all subregions. This landtype lies between narrow ridges, broad uplands, or broad ridges and convex upper slopes (Landtypes 1, 2, and 3) and concave footslopes, terraces, and streambottoms (Landtypes 14 and 15). Slope ranges from 6 to 70 percent. Rock fragments are common on the surface.

Dominant soils—Hartsells, Mountainburg, Hector, Townley, and Montevallo are common in Subregion 3; Lily, Alticrest, Dekalb, Gilpin, and Ramsey are more common in Subregions 1 and 2.

Bedrock—Sandstone, conglomerate, sandstone interbedded with thin strata of siltstone and shale, interbedded shale and sandstone, and siltstone interbedded with sandstone and silty shale.

Depth to bedrock—40 inches and less.

Texture—Loam, fine sandy loam, sandy loam, and silt loam; may be stony, gravelly, shaly, channery, or flaggy. Coarse fragment content ranges from 5 to 65 percent in the solum and generally increases with depth.

Soil drainage—Well drained to somewhat excessively drained.

Relative soil water supply—Medium to high. Irrigated by subsurface flow.

Soil fertility—Moderately low to low.

Vegetation—White oak, scarlet oak, black oak, yellow-poplar, hickories, blackgum, southern red oak, red maple, and chestnut oak; occasional northern red oak, American beech, shortleaf pine, Virginia pine, eastern white pine, loblolly pine, black cherry, white ash, sugar maple, eastern redcedar, eastern hemlock, and black locust. Dogwood, sassafras, sourwood, serviceberry, laurel, vacciniums, viburnums, azaleas, sumac, persimmon, American holly, and smilax are common understory species.

Table 9.—*Forest management interpretations for Landtype 5: North Sandstone slopes. Footnotes appear on page 56.*

PRODUCTIVITY

Species	Site index		Average annual growth cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stand[3]	Old-field plantations[4]
E. white pine	75	52	126	145
Shortleaf pine	60	45	102	102
Loblolly pine	70	55	104	133
Virginia pine	65			
E. redcedar	30		70	
White oak	(65)		48–57	
N. red oak	75			
Yellow-poplar	95		98	
Black cherry	85			
White ash	(85)			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight to moderate	Slight to severe	Slight to severe	Slight to severe	Slight to severe

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
E. white pine	Hickories	E. hemlock
Shortleaf pine	White oak	E. redcedar
Loblolly pine	Chestnut oak	American beech
Virginia pine	Black oak	Sassafras
N. red oak	S. red oak	Serviceberry
Yellow-poplar	Scarlet oak	Black locust
Black cherry	Sugar maple	American holly
White ash		Red maple
		Blackgum
		Dogwood
		Sourwood
		Persimmon

Description of Landtype 6:
South Sandstone Slopes

Geographic setting—Shallow to moderately deep, loamy and clayey soils with a wide range of coarse fragments on sloping to very steep south-facing linear to concave midslopes in all subregions. This landtype lies between narrow ridges, broad uplands, or broad ridges and convex upper slopes (Landtypes 1, 3, and 4) and concave footslopes, terraces, and streambottoms (Landtypes 14 and 15). Slope ranges from 6 to 70 percent. Rock fragments are common on the surface. South-facing slopes tend to be steeper and have shallower soils with higher contents of coarse fragments than north-facing slopes.

Dominant soils—Hartsells, Mountainburg, Hector, Townley, and Montevallo are more common in Subregion 3; Lily, Alticrest, Dekalb, Gilpin, and Ramsey are more common in Subregion 1 and 2.

Bedrock—Sandstone, conglomerate, sandstone interbedded with thin strata of siltstone and shale, interbedded shale and sandstone, and siltstone interbedded with sandstone and silty shale.

Depth to bedrock—40 inches or less.

Texture—Loam, fine sandy loam, sandy loam, and silt loam; may be stony, gravelly, shaly, channery, or flaggy. Coarse fragment content ranges from 5 to 65 percent in the solum and generally increases with depth.

Soil drainage—Well drained to somewhat excessively drained.

Relative soil water supply—Medium to high. Irrigated by subsurface flow.

Soil fertility—Moderately low to low.

Vegetation—White oak, chestnut oak, scarlet oak, southern red oak, post oak, hickories, blackjack oak, black oak, red maple and blackgum; occasional Virginia pine, shortleaf pine, black locust, eastern redcedar, and loblolly pine. Dogwood, sassafras, sourwood, vacciniums, persimmon, smilax, sumac, and viburnums are common understory species.

Table 10.—*Forest management interpretations for Landtype 6: South Sandstone Slopes. Footnotes appear on page 56.*

PRODUCTIVITY

	Site index		Average annual growth cubic feet per acre	
Species	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Shortleaf pine	55	(45)	90	102
Loblolly pine	60	55	86	133
Virginia pine	60		53	
E. redcedar	30			
White oak	60		43–48	
N. red oak	65			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight to moderate	Moderate to severe	Moderate to severe	Moderate to severe	Moderate to severe

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	Loblolly pine	Blackjack oak
Virginia pine	E. redcedar	Sassafras
White oak	Hickories	Black locust
Black oak	Post oak	Red maple
S. red oak	Chestnut oak	Blackgum
	N. red oak	Dogwood
	Scarlet oak	Sourwood
		Persimmon

Description of Landtype 7:
Sandstone Outcrops and Shallow Soils

Geographic setting—Small to moderately large areas of exposed sandstone and conglomerate and shallow loamy soils formed in residuum and locally in some colluvium or alluvium from sandstone, quartzite, and some shale on nearly level to moderately steep ridgetops, slopes, edges of the Plateau above the nearly vertical cliffs, and along deeply incised streams and rivers in all subregions. Landtype 7 also occurs in sinkholes where the thin sandstone caprock has collapsed into underlying limestone caverns, particularly along the strongly dissected western margin (LTA-C) of Subregion 1. Slope ranges from 2 to 70 percent. The area of exposed rock varies from a few square feet to several acres in narrow strips to broad expanses. Slope of the rock surface usually is 5 percent or less. The very shallow dark brown or gray soils at the margins of exposed rock contain a very high percentage of organic matter. This landtype is associated with Landtypes 1 to 6. Landtype 7 has the lowest productivity of any landtype in the region.

Dominant soils—Hector, Ramsey, Mountainburg, and sandstone outcrops.

Bedrock—Predominantly sandstone and conglomerate with thin strata of shale or siltstone in places.

Depth to bedrock—Less than 20 inches.

Texture—Gravelly, channery, and flaggy sandy loam, fine sandy loam, and loam. Coarse fragment content ranges up to 60 percent in the solum and usually increases with depth.

Soil drainage—Well drained to somewhat excessively drained.

Relative soil water supply—Very low. Seepage is common in wet weather, but the soil dries quickly.

Soil fertility—Very low.

Vegetation—White oak, post oak, chestnut oak, blackjack oak, scarlet oak, southern red oak, and blackgum; occasional Virginia pine, shortleaf pine, hickories, red maple, black locust, and eastern redcedar. Sourwood, dogwood, winged elm, mountain-laurel, vacciniums, lichens, mosses, grasses, and buckthorn are common understory species.

Table 11.—*Forest management interpretations for Landtype 7: Sandstone Outcrops and Shallow Soils. Footnotes appear on page 56.*

PRODUCTIVITY

Species	Site index		Average annual growth cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Shortleaf pine	55		90	
Virginia pine	60		53	
E. redcedar	30			
White oak	60		43	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Moderate to severe	Slight to severe	Slight to severe	Severe

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	E. redcedar	Blackjack oak
Virginia pine	Hickories	Winged elm
	White oak	Black locust
	Post oak	Red maple
	Chestnut oak	Blackgum
	S. red oak	Dogwood
	Scarlet oak	Sourwood

Description of Landtype 8:
Broad Shale Ridges—North Aspect

Geographic setting—Moderatly deep to very deep, loamy and clayey soils on gently sloping to steep north-facing, low, broad hills and ridges above the surrounding undulating plateau top. This landtype extends from the ridge crest down to where the gradient usually increases noticeably. Slope ranges from 3 to 35 percent and is dominantly greater than 6 percent. Soils developed in residuum from shale, and siltstone, and thin strata of sandstone. In places there is a 2- to 3-foot layer of loess over the residuum. This landtype occurs in Subregions 1 and 2 mostly north of highway I-40, where the caprock is shale members of the Crooked Fork group. Landtype 8 occurs above upper shale slopes (Landtype 10).

Dominant soils—Sequoia, Gilpin, Wellston, Whitley, and Tilsit.

Bedrock—Shale and siltstone, and thin strata of sandstone in places.

Depth to bedrock—24 to 60 inches or more. Tilsit soils have a fragipan at depths of 18 to 28 inches.

Texture—Silt loam and loam, occasionally silty clay loam; in places, shaly or channery. Coarse fragment content ranges from 0 to 40 percent in the solum, but is commonly less than 25 percent.

Soil drainage—Well drained except Tilsit soils are moderately well drained.

Relative soil water supply—Medium.

Soil fertility—Moderate to moderately low.

Vegetation—White oak, scarlet oak, hickories, black oak, shortleaf pine, and Virginia pine; occasional southern red oak, yellow-poplar, eastern white pine, red maple, blackgum, loblolly pine, black locust, and black cherry. Dogwood, sourwood, sassafras, persimmon, vacciniums, smilax, azaleas, and viburnums are common understory species.

Table 12—*Forest management interpretations for Landtype 8: Broad Shale Ridges—North Aspect. Footnotes appear on page 56.*

PRODUCTIVITY

Species	Site index		Average annual growth cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
E. white pine	80	56	136	172
Shortleaf pine	70		125	
Loblolly pine	80		123	
Virginia pine	70		92	
Yellow-poplar	90		90	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Slight to moderate	Slight to moderate	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
E. white pine	Hickories	Sassafras
Shortleaf pine	Black oak	Black locust
Loblolly pine	S. red oak	Red maple
Virginia pine	Scarlet oak	Blackgum
White oak		Dogwood
Yellow-poplar		Sourwood
Black cherry		Persimmon

Description of Landtype 9:
Broad Shale Ridges—South Aspect

Geographic setting—Moderately deep to very deep, loamy and clayey soils on gently sloping to steep south-facing, low, broad hills and ridges above the surrounding undulating plateau top. This landtype extends from the ridge crest down to where the gradient usually increases noticeably. Slope ranges from 3 to 35 percent and is dominantly greater than 6 percent. Soils developed in residuum from shale and siltstone, and thin strata of sandstone. In places there is a 2- to 3-foot layer of loess over the residuum. This landtype occurs in Subregions 1 and 2 mostly north of highway I-40, where the caprock is shale members of the Crooked Fork group. Landtype 9 occurs above upper shale slopes (Landtype 11).

Dominant soils—Sequoia, Gilpin, Wellston, Whitley, and Tilsit.

Bedrock—Shale and siltstone, and thin strata of sandstone in places.

Depth to bedrock—24 to 60 inches or more. Tilsit soils have a fragipan at depths of 18 to 28 inches.

Texture—Silt loam, loam, and occasionally silty clay loam; in places, shaly or channery. Volume of coarse fragments ranges from 0 to 40 percent in the solum, but it commonly less than 25 percent.

Soil drainage—Well drained except Tilsit soils are moderately well drained.

Relative soil water supply—Medium.

Soil fertility—Moderate to moderately low.

Vegetation—White oak, chestnut oak, scarlet oak, hickories, black oak, shortleaf pine, and Virginia pine; occasional southern red oak, blackjack oak, post oak, eastern white pine, black locust, red maple, blackgum, yellow-poplar, loblolly pine, and black cherry. Dogwood, sourwood, sassafras, persimmon, azaleas, smilax, and viburnums are common understory species.

Table 13—*Forest management interpretations for Landtype 9: Broad Shale Ridges—South Aspect. Footnotes appear on page 56.*

PRODUCTIVITY

Species	Site index: Natural stands[1]	Site index: Old-field plantations[2]	Average annual growth cubic feet per acre: Natural stands[3]	Average annual growth cubic feet per acre: Old-field plantations[4]
E. white pine	(75)	(52)	126	145
Shortleaf pine	(60)		102	
Loblolly pine	(70)		104	
Virginia pine	(65)		70	
Yellow-poplar	80		71	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Slight to moderate	Slight to moderate	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
E. white pine	Hickories	Blackjack oak
Shortleaf pine	Post oak	Sassafras
Loblolly pine	Chestnut oak	Red maple
Virginia pine	S. red oak	Blackgum
White oak	Scarlet oak	Dogwood
Black oak	Black locust	Persimmon
Yellow-poplar		Sourwood
Black cherry		

Description of Landtype 10: Upper Shale Slopes—North Aspect

Geographic setting—Shallow to moderately deep, loamy and shaly soils on moderately steep to very steep, north-facing linear to convex upper slopes. Soils formed in residuum from shale, siltstone, and thin strata of sandstone. Interspersed areas of shale rubble are common. Slope ranges from 10 to 70 percent and is commonly greater than 20 percent. This landtype occurs in Subregions 1 and 2, mostly north of highway I-40, where the caprock is shale members of the Crooked Fork group. Landtype 10 occurs below broad shale ridges (Landtype 8) and above lower shale slopes (Landtype 12).

Dominant soils—Ramsey, Muskingum, Gilpin, and Berks, and shale rubble.

Bedrock—Shale and siltstone; occasionally thin strata of sandstone.

Depth to bedrock—7 to 40 inches.

Texture—Silt loam, loam, and occasionally fine sandy loam; usually shaly or channery. Volume of coarse fragments ranges from 20 to 75 percent in the solum and usually increases in with depth.

Soil drainage—Well drained to somewhat excessively drained.

Relative soil water supply—Medium to low. Irrigated by subsurface flow, but the porous soil drains rapidly.

Soil fertility—Moderate to moderately low.

Vegetation—White oak, scarlet oak, chestnut oak, hickories, yellow-poplar, black oak, red maple, blackgum, and eastern white pine; occasional southern red oak, shortleaf pine, Virginia pine, northern red oak, eastern hemlock, black cherry, white ash, sugar maple, black locust, and loblolly pine. Dogwood, sourwood, sassafras, mountain laurel, persimmon, vacciniums, strawberry bush, devils-walkingstick, striped maple, smilax, azaleas, and viburnums are common understory species.

Table 14.—*Forest management interpretations for Landtype 10: Upper Shale Slopes—North Aspect. Footnotes appear on page 56.*

PRODUCTIVITY

Species	Site index		Average annual growth cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
E. white pine	80	56	136	172
Shortleaf pine	70		125	
Loblolly pine	75		114	
Virginia pine	70		92	
White oak	60		43–57	
N. Red oak	75			
Black oak	70			
Yellow-poplar	95		98	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight to moderate	Slight to moderate	Moderate to severe	Slight to severe	Slight to severe

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
E. white pine	Hickories	E. hemlock
Shortleaf pine	Chestnut oak	Sassafras
Loblolly pine	Black oak	Black locust
Virginia pine	S. red oak	Red maple
White oak	Scarlet oak	Striped maple
N. red oak	Sugar maple	Blackgum
Yellow-poplar	White ash	Dogwood
Black cherry		Sourwood
		Persimmon

Description of Landtype 11:
Upper Shale Slopes—South Aspect

Geographic setting—Shallow to moderately deep, loamy and shaly soils on moderately steep to very steep, south-facing linear to convex upper slopes. Soils formed in residuum from shale, siltstone, and thin strata of sandstone. Areas of shale rubble are common. Slope ranges from 10 to 70 percent and is commonly greater than 20 percent. South-facing slopes tend to be steeper and have shallower soils with higher contents of coarse fragments than north-facing slopes. This landtype occurs in Subregions 1 and 2, mostly north of highway I-40, where the caprock is shale members of the Crooked Fork group. Landtype 11 occurs below broad shale ridges (Landtype 9) and above lower shale slopes (Landtype 13).

Dominant soils—Ramsey, Muskingum, Gilpin, and Berks, and shale rubble.

Bedrock—Shale and siltstone; occasionally thin strata of sandstone.

Depth to bedrock—7 to 40 inches.

Texture—Silt loam, loam, and occasionally fine sandy loam, usually shaly or channery. Volume of coarse fragments ranges from 20 to 75 percent in the solum and usually increases with depth.

Soil drainage—Well drained to somewhat excessively drained.

Relative soil water supply—Medium to low. Irrigated by subsurface flow, but the porous soil drains rapidly.

Soil fertility—Moderate to moderately low.

Vegetation—White oak, scarlet oak, chestnut oak, hickories, Virginia pine, shortleaf pine, black oak, and post oak; occasional southern red oak, blackjack oak, eastern white pine, red maple, black locust, blackgum, and loblolly pine. Dogwood, sourwood, sassafras, laurel, vacciniums, smilax, persimmon, azaleas, and viburnums are common understory species.

Table 15.—*Forest management interpretations for Landtype 11: Upper Shale Slopes—South Aspect. Footnotes appear on page 56.*

PRODUCTIVITY

Species	Site index: Natural stands[1]	Site index: Old-field plantations[2]	Average annual growth cubic feet per acre: Natural stands[3]	Average annual growth cubic feet per acre: Old-field plantations[4]
E. white pine	70	49	115	126
Shortleaf pine	60		102	
Loblolly pine	(65)		95	
Virginia pine	60		53	
Black oak	60		43	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight to moderate	Slight to moderate	Moderate to severe	Slight to severe	Slight to severe

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
E. white pine	Hickories	Blackjack oak
Shortleaf pine	Post oak	Sassafras
Loblolly pine	Chestnut oak	Black locust
Virginia pine	S. red oak	Red maple
White oak	Scarlet oak	Blackgum
Black oak		Dogwood
		Sourwood
		Persimmon

Description of Landtype 12:
Lower Shale Slopes—North Aspect

Geographic setting—Deep to very deep, shaly or gravelly, loamy soils formed in colluvium from shale, siltstone, and in places, sandstone, and underlain by shale, siltstone, and sandstone. This landtype occupies the moderately steep to very steep, north-facing lower concave clopes. Slope ranges from 5 to 60 percent, but is commonly greater than 20 percent. This landtype occurs in Subregions 1 and 2, mostly north of highway I-40, where the caprock is shale members of the Crooked Fork group. This landtype occurs below upper shale slopes (Landtype 10) and merges with footslopes, terraces, and streambottoms (Landtypes 14 and 15).

Dominant soils—Jefferson and Shelocta.

Bedrock—Shale, siltstone, and some sandstone.

Depth to bedrock—more than 40 inches up to 120 inches.

Texture—Loam and silt loam; sometimes sandy clay loam, and clay loam; usually shaly or channery, sometimes gravelly. Coarse fragment content ranges from 5 to 80 percent in the solum and increases with depth.

Soil drainage—Well drained.

Relative soil water supply—Medium to high. Irrigated by subsurface flow; wet weather seeps are common.

Soil fertility—Moderate to moderately low.

Vegetation—White oak, northern red oak, yellow-poplar, hickories, black oak, eastern white pine, eastern hemlock, blackgum, and red maple; occasional Virginia pine, shortleaf pine, scarlet oak, southern red oak, chestnut oak, black cherry, sugar maple, white ash, black locust, bigleaf magnolia, and loblolly pine. Dogwood, sourwood, sassafras, mountain laurel, rhododendron, witch-hazel, azaleas, viburnums, persimmon, strawberry bush, devils-walkingstick, striped maple, and spicebush are common understory species.

Table 16.—*Forest management interpretations for Landtype 12: Lower Shale Slopes—North Aspect. Footnotes appear on page 56.*

PRODUCTIVITY

Species	Site index		Average annual growth cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Shortleaf pine	75		136	
Loblolly pine	85		134	
Virginia pine	75		120	
N. red oak	75		57	
Yellow-poplar	100		107	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Slight	Moderate to severe	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
E. white pine	Hickories	E. hemlock
Shortleaf pine	Chestnut oak	Bigleaf magnolia
Loblolly pine	Black oak	Sassafras
Virginia pine	S. red oak	Black locust
White oak	Scarlet oak	Red maple
N. red oak	Sugar maple	Striped maple
Yellow-poplar	White ash	Blackgum
Black cherry		Dogwood
		Sourwood
		Persimmon

Description of Landtype 13:
Lower Shale Slopes—South Aspect

Geographic setting—Deep to very deep, shaly or gravelly, loamy soils formed in colluvium from shale, siltstone, and in places, sandstone, and underlain by shale, siltstone, and sandstone. This landtype occupies the moderately steep to very steep, south-facing lower concave slopes. Slope ranges from 5 to 60 percent, but is commonly greater than 20 percent. South-facing slopes tend to be steeper and have shallower soils with higher contents of coarse fragments than north-facing slopes. This landtype occurs in Subregions 1 and 2, mostly north of highway I-40, where the caprock is shale members of the Crooked Fork group. This landtype occurs below upper shale slopes (Landtype 11) and merges with footslopes, terraces, and streambottoms (Landtypes 14 and 15).

Dominant soils—Jefferson and Shelocta.

Bedrock—Shale, siltstone, and some sandstone.

Depth to bedrock—More than 40 inches up to 120 inches.

Texture—Loam and silt loam; sometimes sandy clay loam, and clay loam; usually shaly or channery, sometimes gravelly. Coarse fragment content ranges from 5 to 80 percent in the solum and increases with depth.

Relative soil water supply—Medium to high. Irrigated by subsurface flow; wet weather seeps are common, but duration is short during the growing season.

Soil fertility—Moderate to moderately low.

Vegetation—White oak, scarlet oak, chestnut oak, hickories, black oak, blackgum, red maple, Virginia pine, and shortleaf pine; occasional southern red oak, eastern white pine, yellow-poplar, northern red oak, post oak, black locust, black cherry, and loblolly pine. Dogwood, sassafras, sourwood, rhododendron, vacciniums, azaleas, strawberry bush, devils-walkingstick, striped maple, and viburnums are common understory species.

Table 17.—*Forest management interpretations for Landtype 13: Lower Shale Slopes—South Aspect. Footnotes appear on page 56.*

PRODUCTIVITY

Species	Site index		Average annual growth cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Shortleaf pine	65		113	
Loblolly pine	80		123	
Virginia pine	70		92	
N. red oak	65		48	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Slight	Moderate to severe	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
E. white pine	Hickories	Post oak
Shortleaf pine	Chestnut oak	Sassafras
Loblolly pine	Black oak	Black locust
Virginia pine	S. red oak	Red maple
White oak	Scarlet oak	Striped maple
N. red oak	Black cherry	Blackgum
S. red oak		Dogwood
Yellow-poplar		Sourwood

Description of Landtype 14: Footslopes, Terraces, and Streambottoms with Good Drainage

Geographic setting—Deep, loamy soils with good drainage on level to strongly sloping concave footslopes, stream terraces, and heads of hollows on the Plateau surface in all subregions. Slope ranges from 0 to 15 percent. This landtype typically occurs below Landtypes 5, 6, 12, and 13 as narrow strips along intermittent drainages or level bottomland along permanent streams, creeks, and rivers but can also occur below Landtypes 1, 2, 3, 8, and 9 near the heads of streams. When Landtypes 14 and 15 are adjacent, Landtype 14 occupies a higher position on the landscape. In gorges of the Plateau interior, particularly in LTA-C of Subregion 1, this landtype occurs below Landtypes 16 and 17 where streams have not cut through the sandstone caprock, and below Landtypes 18 and 19 where streams have cut through the sandstone caprock into the underlying Pennington and Bangor formations. This landtype is the second most productive one in the region.

Dominant soils—Sewanee, Clifty, Ealy, Cotaco, Barbourville, Pope, and Philo.

Parent material—Alluvium, and in places, colluvium from soils developed in residuum from sandstone, siltstone, and shale, and underlain by sandstone, siltstone, shale, and limestone.

Depth to bedrock—40 inches to 12 feet or more.

Texture—Loam, fine sandy loam, silt loam, and sandy loam; occasionally gravelly. Coarse fragment content ranges from 0 to 35 percent and usually increases with depth.

Soil drainage—Moderately well drained to well drained.

Relative soil water supply—High. Irrigated by subsurface flow. Seeps occur on footslopes in winter and spring. Streambottoms may have seasonal water table for 1 to 3 months.

Soil fertility—Moderate.

Vegetation—White oak, yellow-poplar, red maple, blackgum, sweetgum, black oak, and loblolly pine; occasional southern red oak, scarlet oak, eastern white pine, eastern hemlock, shortleaf pine, Virginia pine, bigleaf magnolia, American sycamore, American elm, American beech, and hackberry. Dogwood, sassafras, sourwood serviceberry, blue-beech, mountain-laurel, viburnums, strawberry bush, devils-walkingstick, striped maple, azaleas, cane, and American holly are common in the understory.

Table 18.—*Forest management interpretations for Landtype 14: Footslopes, Terraces, and Streambottoms with Good Drainage. Footnotes appear on page 56.*

PRODUCTIVITY

Species	Site index		Average annual growth cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
E. white pine	90	63	154	226
Shortleaf pine	80	(50)	148	117
Loblolly pine	85	60	134	148
Virginia pine	75		120	
Upland oaks	80		62	
Yellow-poplar	100		107	
Sweetgum	90		81	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Severe	Slight	Slight to moderate	Slight	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
E. white pine	White oak	E. hemlock
Shortleaf pine	Black oak	American hornbeam
Loblolly pine	S. red oak	American beech
Virginia pine	Scarlet oak	Hackberry
Yellow-poplar	American elm	Bigleaf magnolia
Sweetgum		Sassafras
American sycamore		Serviceberry
		American holly
		Red maple
		Striped maple
		Blackgum
		Dogwood
		Sourwood

Description of Landtype 15: Terraces, Streambottoms, and Depressions with Poor Drainage

Geographic setting—Deep, loamy soils with poor drainage on level to gently sloping stream terraces, heads of hollows, and depressions on the Plateau surface in Subregions 1, 2, and 3. Slope ranges from 0 to 3 percent. This landtype typically occurs below Landtypes 5, 6, 12, and 13 as narrow strips along intermittent drainages or level bottomland along permanent streams, creeks, and rivers but can also occur below Landtypes 1, 2, 3, 8, and 9 near the heads of streams. When landtypes 14 and 15 are adjacent, Landtype 14 occupies a higher position on the landscape. In gorges on the Plateau interior, particularly in Subregion 1, this landtype occurs below Landtypes 16 and 17 where streams have not cut through the sandstone caprock, and below Landtype 18 and 19 where streams have cut through the caprock into the underlying Pennington and Bangor formations.

Dominant soils—Bonair, Atkins, and Stokly.

Parent material—Alluvium washed from soils developed in residuum from sandstone, siltstone, and shale, and underlain by sandstone, siltstone, shale, and limestone.

Depth to bedrock—40 inches to 5 feet or more.

Texture—Loam, fine sandy loam, silt loam, and sandy loam; occasionally silty clay loam. Coarse fragment content ranges from 0 to 20 percent in the solum and usually increases with depth.

Soil drainage—Poorly drained to somewhat poorly drained.

Relative soil water supply—High to very high. Irrigated by subsurface flow. Subject to flooding for brief periods and has a water table within a foot or less of the surface from January to May.

Soil fertility—Moderate.

Vegetation—Red maple, sweetgum, blackgum, yellow-poplar, white oak, American sycamore, and loblolly pine; occasional American elm, American beech, cottonwood, water oak, willow oak, black willow, and boxelder. Viburnums, azaleas, mountain-laurel, American holly, cane, sphagnum moss, alder, dogwood, buckthorn, strawberry bush, Virginia-willow, and sedges are common in the understory.

Table 19—*Forest management interpretations for Landtype 15: Terraces, Streambottoms and Depressions with Poor Drainage. Footnotes appear on page 56.*

PRODUCTIVITY

Species	Site index		Average annual growth cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Loblolly pine	85	70	134	175
Cottonwood	105			
Bottomland oaks	90			
Yellow-poplar	90		90	
Sweetgum	90		81	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate to severe	Moderate to severe	Severe	Slight	Slight to moderate

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Cottonwood	Loblolly pine	Black willow
Willow oak	White oak	American beech
Water oak	American elm	American holly
Sweetgum	Yellow-poplar	Red maple
	American sycamore	Boxelder
		Blackgum
		Dogwood

Description of Landtype 16:
Plateau Escarpment and Upper Sandstone Slopes and Benches—North Aspect

Geographic setting—Deep to very deep, loamy soils formed in colluvium from sandstone, siltstone, and shale, and underlain by sandstone, siltstone, or shale in all subregions. Occupies the gently sloping to very steep upper one-third to one-half of northerly slopes that extend from the Plateau escarpment to the adjacent limestone valleys. Slope ranges from 5 to 70 percent. Much of the surface is covered with sandstone boulders and fragments. At the Plateau exterior, particularly in the Sequatchie Valley, this landtype may be absent if escarpment development has progressed down to limestone. In gorges of the Plateau interior, primarily in Subregion 1, where stream cutting has not carved through the sandstone caprock, this landtype occurs between the escarpment and larger streams and rivers and Landtype 18 is absent. In narrow gorges the lower one-fourth to one-half of south-facing slopes (Landtype 17) should be included with Landtype 16 because shading mollifies the normal warm microclimate. This landtype is a mesic site and has the highest productivity of any landtype in the region.

Dominant soils—Grimsley, Jefferson, Ramsey, and Zenith. Formerly mapped as sandstone rockland or bouldery colluvial land.

Bedrock—Sandstone, siltstone, and shale.

Depth to bedrock—40 to 60 inches or more.

Texture—Gravelly or cobbly loam, silt loam, sandy clay loam, or clay loam.

Soil drainge—well drained.

Relative soil water supply—Very high to high. Irrigated by subsurface flow and seepage.

Soil fertility—Moderate to moderately low.

Vegetation—White oak, northern red oak, yellow-poplar, chestnut oak, sugar maple, hickories, American beech, black oak, white ash, white basswood, yellow buckeye, and black locust; occasional blackgum, elms, red maple, southern red oak, eastern hemlock, eastern white pine, chinkapin oak, black cherry, black walnut, and cucumbertree. Dogwood, eastern redbud, bigleaf magnolia, specebush, bladdernut, hydrangea, viburnums, azaleas, rhododendrons, sourwood, grape, and pawpaw are common understory species. This landtype also supports a rich herbaceous flora.

Table 20.—*Forest management interpretations for Landtype 16: Plateau Escarpment and Upper Sandstone Slopes and Benches—North Aspect. Footnotes appear on page 56.*

PRODUCTIVITY

Species	Site index		Average annual growth cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Black walnut	(90)			
White oak	75		57–62	
N. red oak	80			
S. red oak	75			
Yellow-poplar	100		107	
Black cherry	(90)			
White ash	(90)			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Moderate	Slight	Slight to severe	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Black walnut	E. white pine	E. hemlock
White oak	Chinkapin oak	American beech
N. red oak	Black oak	E. redbud
Yellow-poplar	S. red oak	Black locust
Black cherry	Elms	Red maple
White ash	Cucumbertree	Blackgum
	Sugar maple	Dogwood
	Yellow buckeye	Sourwood
	White basswood	

Description of Landtype 17:
Plateau Escarpment and Upper Sandstone Slopes and Benches—South Aspect

Geographic setting—Deep to very deep, loamy soils formed in colluvium from sandstone, siltstone, and shale, and underlain by sandstone, siltstone, or shale in all subregions. Occupies the gently sloping to very steep upper one-third to one-half of southerly slopes that extend from the Plateau escarpment to the adjacent limestone valleys. Slope ranges from 5 to 70 percent. Much of the surface is covered with sandstone boulders and fragments. At the Plateau exterior, particularly in the Sequatchie Valley, this landtype may be absent if escarpment development has progressed down to limestone. In gorges of the Plateau interior, primarily in Subregion 1, where stream cutting has not carved through the sandstone caprock, this landtype occurs between the escarpment and larger steams and rivers and landtype 19 is absent. In narrow gorges the lower one-fourth to one-half of these slopes should be included in Landtype 16 because shading mollifies the normal warm microclimate. This landtype is not as productive as Landtype 16, and forests lack the preponderance of mesic species found on north aspects.

Dominant soils—Grimsley, Ramsey, Jefferson. Formerly mapped as sandstone rockland or bouldery colluvial land.

Bedrock—Sandstone, siltstone, and shale.

Depth to bedrock—40 to 60 inches or more.

Texture—Gravelly or cobbly loam, silt loam, sandy clay loam, or clay loam.

Soil drainage—Well drained.

Relative soil water supply—Medium to low. Irrigated by subsurface flow and seepage. This landtype is not as moist as Landtype 16.

Soil fertility—Moderately low to low.

Vegetation—White oak, chestnut oak, northern red oak, hickories, black oak, red maple, yellow-poplar, and black locust; occasional blackgum, elms, eastern white pine, white ash, black cherry, black walnut, sugar maple, southern red oak, shortleaf pine, Virginia pine, loblolly pine, and American beech. Dogwood, viburnums, eastern redbud, sourwood, azaleas, and grape are common understory species.

Table 21.—*Forest management interpretations for Landtype 17: Plateau Escarpment and Upper Sandstone Slopes and Benches—South Aspect. Footnotes appear on page 56.*

PRODUCTIVITY

Species	Site index		Average annual growth cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Shortleaf pine	65		113	
Loblolly pine	(75)		114	
Virginia pine	70		92	
White oak	(65)		43–48	
N. red oak	60			
S. red oak	(65)			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Moderate	Slight to severe	Slight to moderate	Slight

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
E. white pine	Black walnut	American beech
Shortleaf pine	Hickories	E. redbud
Loblolly pine	Black locust	Red maple
Virginia pine	N. red oak	Blackgum
White oak	Elms	Dogwood
Chestnut oak	Yellow-poplar	Sourwood
Black oak	Black cherry	
S. red oak	Sugar maple	
	White ash	

Description of Landtype 18:
Lower Limestone Slopes, Benches, and Spur Ridges—North Aspect

Geographic setting—Moderately deep to very deep, loamy and clayey soils formed from limestone residuum and some colluvium from sandstone, siltstone, and shale and underlain by limestone in all subregions. Occupies the gently sloping to very steep lower one-half to two-thirds of northerly slopes that extend from the Plateau escarpment to the adjacent limestone valleys, or the entire northern slopes of narrow spur ridges that extend into the adjacent valleys. Slope ranges from 2 to 75 percent. Sandstone boulders may be present, but up to 40 percent of the surface is covered with outcrops of limestone. Soil material between the rocks is compact, sticky, heavy clay. Coarse fragments in the soil vary from less than 10 percent to 65 percent. This landtype usually occurs downslope from Landtype 16 and is less productive than north upper slopes. Landtype 20 often occurs below this landtype on footslopes dominated by limestone outcrops. Where the escarpment has developed down to limestone, however, this landtype extends from the base of the escarpment down to the adjoining valleys. This landtype is absent in gorges of the Plateau interior where streams have not cut through the sandstone caprock. Where streams have cut through the sandstone caprock into the underlying Pennington and Bangor formations, this landtype occurs below Landtype 16 and above Landtypes 14 and 15. In deeply cut, narrow gorges the lower one-fourth to one-half of south-facing slopes (Landtype 19) should be included with Landtype 18 because shading mollifies the normal warm microclimate.

Dominant soils—Bouldin, Allen, Nella, and Talbott. Formerly mapped as limestone rockland or bouldery colluvial land.

Bedrock—Limestone.

Depth to bedrock—Mostly 60 inches or more but may be 20 to 40 inches where Talbott soils occur.

Texture—Cobbly to stony loam, sandy loam, clay loam, and silt loam.

Soil drainage—Well drained.

Relative soil water supply—Medium to low. Soil water percolates deep into the limestone.

Soil fertility—Moderate to moderately low.

Vegetation—White oak, chestnut oak, northern red oak, black oak, hickories, scarlet oak, southern red oak, and yellow-poplar; occasional blackgum, red maple, sugar maple, eastern white pine, post oak; chinkapin oak, and elms. Dogwood, eastern redbud, winged elm, viburnums, sumac, ironwood, and hawthorns are common in the understory.

Table 22.—*Forest management interpretations for Landtype 18: Lower Limestone Slopes, Benches, and Spur Ridges—North Aspect. Footnotes appear on page 56.*

PRODUCTIVITY

Species	Site index		Average annual growth cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
White oak	70		43–52	
N. red oak	70			
S. red oak	60			
Yellow-poplar	85		80	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight to moderate	Slight to moderate	Slight to severe	Slight to moderate	Slight to moderate

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
White oak	E. white pine	Ironwood
N. red oak	Hickories	Winged elm
Black oak	Post oak	E. redbud
S. red oak	Chestnut oak	Blackgum
Yellow-poplar	Chinkapin oak	Dogwood
	Scarlet oak	
	Elms	
	Sugar maple	

Description of Landtype 19:
Lower Limestone Slopes, Benches, and Spur Ridges—South Aspect

Geographic setting—Moderately deep to very deep, loamy and clayey soils formed in colluvium from sandstone, siltstone, and shale and from limestone residuum, and underlain by limestone in all subregions. Occupies the gently sloping to very steep lower one-half to two-thirds of southerly slopes that extend from the Plateau escarpment to the adjacent limestone valleys, or the entire southerly slopes of narrow spur ridges that extend into the adjacent valleys. Slope ranges from 2 to 75 percent. Sandstone boulders may be present, but up to 40 percent of the surface is covered with outcrops of limestone. Soil material between the rocks is compact, sticky, heavy clay. Coarse fragments in the soil vary from less than 10 percent to 65 percent. This landtype usually occurs downslope from Landtype 17 and is less productive than south upper slopes. Landtype 20 often occurs below this landtype on footslopes dominated by limestone outcrops. Where the escarpment has developed down to limestone, however, this landtype extends from the base of the escarpment down to the adjoining valleys. This landtype is absent in gorges of the Plateau interior where streams have not cut through the sandstone caprock. Where streams have cut through the sandstone caprock into the underlying Pennington and Bangor formations, this landtype occurs below Landtype 17 and above Landtypes 14 and 15. In deeply cut, narrow gorges the lower one-fourth to one-half of these slopes should be included in Landtype 18 because shading mollifies the normal warm microclimate.

Dominant soils—Bouldin, Allen, Nella, and Talbott. Formerly mapped as limestone rockland or bouldery colluvial land.

Bedrock—Limestone.

Depth to bedrock—Mostly 60 inches or more but may be 20 to 40 inches where Talbott soils occur.

Texture—Cobbly to stony loam, sandy loam, clay loam, and silt loam.

Soil drainage—Well drained.

Relative soil water supply—Low to very low. Soil water percolates deep into the limestone.

Soil fertility—Moderate to moderately low.

Vegetation—White oak, scarlet oak, chestnut oak, hickories, eastern redcedar, white ash, post oak, southern red oak, black oak, and elms; occasional red maple, blackgum, black locust, chinkapin oak, honeylocust, blue ash, American beech, Virginia pine, shortleaf pine, and loblolly pine. Eastern redbud, dogwood, winged elm, viburnums, ironwood, hawthorns, and sumac are common in the understory.

Table 23.—*Forest management interpretations for Landtype 19: Lower Limestone Slopes, Benches, and Spur Ridges—South Aspect. Footnotes appear on page 56.*

PRODUCTIVITY

Species	Site index		Average annual growth cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Shortleaf pine	55		90	
Loblolly pine	(65)		95	
Virginia pine	60		53	
E. redcedar	45			
White oak	50		32–38	
S. red oak	55			

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Moderate to severe	Moderate to severe	Slight to moderate	Slight to moderate

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Shortleaf pine	E. redcedar	Ironwood
Loblolly pine	Hickories	American beech
Virginia pine	Post oak	Winged elm
White oak	Chestnut oak	E. redbud
S. red oak	Chinkapin oak	Honeylocust
White ash	Black oak	Red maple
	Scarlet oak	Blackgum
	Elms	Dogwood
	Black locust	
	Blue ash	

Description of Landtype 20:
Limestone Outcrops and Shallow Soils

Geographic setting—Small to extensive areas of limestone outcrops interspersed with patches of shallow to moderately deep, clayey soils on gently sloping to steep footslopes in all subregions. This intricate pattern of soil and rock outcrops occurs mostly between Landtypes 18 and 19 and the adjacent limestone valleys but may occur intermingled with Landtypes 18 and 19. Eastern redcedar often dominantes this landtype. Slope ranges from 2 to 40 percent. Soil mass may contain up to 65 percent limestone slabs. More than 50 percent of the surface may be exposed limestone. Where the exposed rock is extensive, it is often terraced but the slope of each terrace is nearly horizontal.

Dominant soils—Barfield, Gladeville, and limestone rockland. Pockets of moderately deep Talbott may occur in this landtype.

Bedrock—Limestone.

Depth to bedrock—Mostly less than 20 inches but ranges up to 40 inches where Talbott soils occur.

Texture—Silty clay loam, silty clay, clay, and silt loam.

Soil drainage—Well drained to excessively drained.

Relative soil water supply—Low. Seepage is common in wet weather, but the soil dries quickly.

Fertility—Moderate.

Vegetation—Eastern redcedar, hickories, hackberry, white ash, and elms; occasional honeylocust, Virginia pine, blackjack oak, blue ash, black wlanut, southern red oak, and osage-orange. Forbs, grasses, sumac, eastern redbud, winged elm, buckthorn, hawthorns, and pricklypear are common in the understory.

Table 24.—*Forest management interpretations for Landtype 20: Limestone Outcrops and Shallow Soils. Footnotes appear on page 56.*

PRODUCTIVITY

Species	Site index		Average annual growth cubic feet per acre	
	Natural stands[1]	Old-field plantations[2]	Natural stands[3]	Old-field plantations[4]
Virginia pine	(55)		41	
E. redcedar	40			
Upland oaks	(55)		38	

MANAGEMENT PROBLEMS

Plant competition	Seedling mortality	Equipment limitations	Erosion hazard	Windthrow hazard
Slight	Severe	Moderate to severe	Moderate	Moderate to severe

SPECIES DESIRABILITY

Most desirable	Acceptable	Least desirable
Virginia pine	Hickories	Blackjack oak
E. redcedar	Elms	Winged elm
Black walnut	White ash	Hackberry
S. red oak	Blue ash	Osage-orange
		E. redbud
		Honeylocust

Footnotes for Tables 5–24

[1] Site indices for each naturally occurring species, except those enclosed in parentheses, are the means of values from soil survey interpretations issued by the SCS for the dominant soils in each landtype, but sometimes adjusted for aspect and slope position (Beck 1962; Broadfoot 1960, 1963; Broadfoot and Krinard 1959; Curtis and Post 1962; Defler 1937; Doolittle and Vimmerstedt 1960; Nelson and others 1961; Schnur 1937; and U.S. Forest Service 1929). Estimated site indices are enclosed in parentheses. Base age is 50 yrs for all naturally grown species except cottonwood, for which it is 30 yrs.

[2] Site indices for old-field plantations of eastern white, loblolly, and shortleaf pines were obtained from Vimmerstedt's (1962) and Smalley and Bower's (1971) site curves. Base age is 25 yrs from seed.

[3] Annual growth of natural stands calculated from published yields at 50 yrs: Eastern white pine—(Doolittle 1956), inside bark volume of total stem, all trees; Shortleaf and loblolly pines—(U.S. Forest Service 1929, Tables 44 and 108), total volume outside bark, trees > 3.5 inches d.b.h.; Virginia pine—(Nelson and others, 1961, Table 4), outside-bark volume to a 4.0-inch o.b. top, trees > 3.5 inches d.b.h.; Upland oaks — (Schnur 1937, Table 2, Column 12), outside bark volume to a 4.0-inch o.b. top, trees > 4.5 inches d.b.h.; Yellow-poplar—(McCarthy 1933, Table 17), inside-bark volume to a 3.0-inch i.b. top, trees > 4.5 inches d.b.h.; Sweetgum—(Winters and Osborne 1935, Table 13), inside-bark volume to a 4.0-inch i.b. top, trees >4.5 inches d.b.h.

[4] Annual growth of eastern white pine plantations calculated from yields at 35 yrs assuming an original spacing of 6 × 7 feet (1,037 trees per ac), outside-bark volume to a 3.0-inch o.b. top, trees > 3.0 inches d.b.h. (Vimmerstedt 1962). Annual growth of loblolly and shortleaf pine plantations calculated from yields at 40 yrs assuming 1,000 seedlings planted per ac., outside-bark volume to a 4.0-inch o.b. top, trees > 4.5 inches d.b.h. (Smalley and Bailey 1974a, 1974b).

LITERATURE CITED

Beck, D. E.
1962. Yellow-poplar site index curves. U.S. Dep. Agric. For. Serv., Res. Note 180. Southeast. For. Exp. Stn., Asheville, N.C. 2 p.

Beeman, L .E.
1978. Computer-assisted resource management. *In.* Integrated Inventories of Renewable Natural Resources: Proceedings of the Workshop, p. 375–381. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. RM-55. Rocky Mountain For. Range Exp. Stn., Fort Collins, Colo.

Braun, E. L.
1950. Deciduous forests of eastern North America. The Blakiston Co., Philadelphia. 596 p.

Broadfoot, W. M.
1960. Field guide for evaluating cottonwood sites. U.S. Dep. Agric. For. Serv., Occas. Pap. 178. South. For. Exp. Stn., New Orleans, La. 6 p.

Broadfoot, W. M.
1963. Guide for evaluating water oak sites. U.S. Dep. Agric. For. Serv., Res. Pap. S0-1. South. For. Exp. Stn., New Orleans, La. 8 p.

Broadfoot, W. M., and R. M. Krinard.
1959. Guide for evaluating sweetgum sites. U.S. Dep. Agric. For. Serv., Occas. Pap. 176. South. For. Exp. Stn., New Orleans, La. 6 p.

Caplenor, D.
1979. The woody plants of the gorges of the Cumberland Plateau and adjacent Highland Rim. J. Tenn. Acad. Sci. 54:139–145.

Carmean, W. H.
1975. Forest site quality evaluation in the United States. Adv. Agron. 27:209–269.

Curtis, R. O., and B. W. Post
1962. Site index curves for even-aged northern hardwoods in the Green Mountains of Vermont. Vt. Agric. Exp. Stn. Bull. 629, 11 p.

Defler, S.E.
1937. Black cherry: Characteristics, germination, growth, and yield. M. F. Thesis, New York State Coll. Forestry, Syracuse. 129 p.

Doolittle, W. T.
1956. Yield tables for white pine. (Unpublished data adapted from Gevorkiantz, S. R. and R. Zon. Second growth white pine in Wisconsin. Wis. Agric. Exp. Stn. Res. Bull. 98, 40 p. 1930). U.S. Dep. Agric. For. Serv., Southeast. For. Exp. Stn., Asheville, N.C.

Doolittle, W. T.
1958. Site index comparisons for several forest species in the Southern Appalachians. Soil Sci. Soc. Am. Proc. 22:455–458.

Doolittle, W. T. and J. P. Vimmerstedt.
1960. Site index curves for natural stands of white pine in the Southern Appalachians. U.S. Dep. Agric. For. Serv., Res. Note 141. Southeast. For. Exp. Stn., Asheville, N.C. 2 p.

Elder, J. A., and M. E. Springer
1978. General soil map, Tennessee. U.S. Dep. Agric.,

Soil Conserv. Serv. in cooperation with Tenn. Agric. Exp. Stn.

Fenneman, N. M.
1938. Physiography of eastern United States. McGraw-Hill, New York. 714 p.

Fernald, M. L.
1950. Gray's manual of botany. Ed. 8, New York: Am. Book Co. 1,632 p.

Francis, J. K., and N. S. Loftus.
1977. Chemical and physical properties of Cumberland Plateau and Highland Rim forest soils. U.S. Dep. Agric. For. Serv., Pap. S0-138. South. For. Exp. Stn., New Orleans, La. 44 p.

Hajek, B. F., F. L. Gilbert, and C. A. Steers.
1975. Soil associations of Alabama. Agron. and Soil Departmental Series No. 24, 30 p + map. Agric. Exp. Stn., Auburn Univ. and U.S. Dep. Agric. Soil Conserv. Serv.

Hedlund, A., and J. W. Earles.
1971. Forest statistics for Tennessee counties. U.S. Dep. Agric. For. Serv., Resour. Bull. S0-32. South. For. Exp. Stn., New Orleans, La. 58 p.

Hedlund, A., and J. W. Earles.
1973. Forest statistics for Alabama counties. U.S. Dep. Agric. For. Serv., Resour. Bull. S0-39. South. For. Exp. Stn., New Orleans, La. 65 p.

Johnson, E. W., and L. R. Sellman.
1979. Forest cover photo-interpretation key for the Cumberland Plateau forest habitat region in Alabama. Auburn Univ. (Ala.) Agric. Exp. Stn. Forestry Dept. Series No. 10, 79 p.

Knetsch, J. L., and J. Smallshaw.
1958. The occurrence of drought in the Tennessee Valley. Bull. T 58-2 AE, 58 p. Tenn. Val. Auth.

Lane, C. F.
1953. The geology of Grassy Cove, Cumberland County, Tennessee. J. Tenn. Acad. Sci. 28:109–117.

Little, E. L., Jr.
1979. Checklist of United States trees (native and naturalized). U.S. Dep. Agric., Agric. Handb. 541. 375 p.

Luther, E. T.
1977. Our restless earth: The geologic regions of Tennessee. Univ. Tennessee Press, Knoxville. 94 p.

McCarthy, D. M.
1976. Numerical techniques for classifying forest communities in the Tennessee Valley. Ph.D. Diss., Univ. Tenn., Knoxville. 164 p. (Univ. Microfilms, Ann Arbor, Mich.)

McCarthy, E. F.
1933. Yellow poplar characteristics, growth, and management. U.S. Dep. Agric., Tech. Bull. No. 356. 58 p.

Quarterman, E., B. H. Turner, and T. E. Hemmerly.
1972. Analysis of virgin mixed mesophytic forests in Savage Gulf, Tennessee. Bull. Torrey Bot. Club 99:228–232.

Nelson, T. E., J. L. Clutter, and L. E. Chaiken.
1961. Yield of Virginia pine. U. S. Dep. Agric. For. Serv., Stn. Pap. 124. Southeast. For. Exp. Stn., Asheville, N.C. 11 p.

Schmalzer, P. A., C. R. Hinkle, and H. R. DeSelm.
1978. Discriminant analysis of cove forests of the Cumberland Plateau of Tennessee. *In.* P. E. Pope (ed.), Proc. Second Cent. Hdwd. For. Conf., p. 62–86. Purdue Univ., Ind. Nov. 14–16, 1978.

Schnur, G. L.
1937. Yield, stand, and volume tables for even-aged upland oak forests. U.S. Dep. Agric. Tech. Bull. 560, 87 p. (Reprinted 1961).

Smalley, G. W.
1978. Classification and evaluation of forest sites in the Interior Uplands. *In.* P. E. Pope (ed.), Proc. Second. Cent. Hdwd. For. Conf., Addendum p. Smalley 1–20. Purdue Univ., Ind. Nov. 14–16, 1978.

Smalley, G. W.
1979a. Classification and evaluation of forest sites for timber production: Introduction of a new system for classifying forest sites based on the physical features of the landscape. *In* Forest Soils and Site Quality Workshop, p. 28–47. Auburn. Univ., Alabama, May 8–9, 1979.

Smalley, G. W.
1979b. Classification and evaluation of forest sites on the southern Cumberland Plateau. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. S0-23. South. For. Exp. Stn., New Orleans, La. 59 p.

Smalley, G. W.
1980. Classification and evaluation of forest sites on the Western Highland Rim and Pennyroyal. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. S0-30. South. For. Exp. Stn., New Orleans, La. 120 p.

Smalley, G. W., and R. L. Bailey
1974a. Yield tables and stand structure for loblolly pine plantations in Tennessee, Alabama, and Georgia highlands. U.S. Dep. Agric. For. Serv., Res. Pap. S0-96. South. For. Exp. Stn., New Orleans, La. 81 p.

Smalley, G. W., and R. L. Bailey
1974b. Yield tables and stand structure for shortleaf pine plantations in Tennessee, Alabama, and Georgia highlands. U.S. Dep. Agric. For. Serv., Res. Pap. S0-97. South. For. Exp. Stn., New Orleans, La. 57 p.

Smalley, G. W., and D. R. Bower.
1971. Site index curves for loblolly and shortleaf pine plantations on abandoned fields in Tennessee, Alabama, and Georgia highlands. U.S. Dep. Agric. For. Serv., Res. Note S0-126. South. For. Exp. Stn., New Orleans, La. 6 p.

Smith, L. R.
1977. The swamp and mesic forests of the Cumber-

land Plateau in Tennessee. M. S. Thesis, Univ. of Tenn., Knoxville. 121 p.

Soil Survey Staff.
1951. Soil survey manual. U.S. Dep. Agric., Agric. Handb. 18. 503 p.

Soil Survey Staff.
1975. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. U.S. Dep. Agric. Soil Conserv. Serv., Agric. Handb. 436. 754 p.

Swingle, G. D., R. A. Miller, E. T. Luther, W. D. Hardeman, D. S. Fullerton, C. R. Sykes, and R. K. Garman (Compilers)
1966. Geology map of Tennessee, east-central sheet. Scale 1:250,000. State of Tenn., Dept. of Conserv., Div. of Geol.

Thornwaite, C. W.
1948. An approach toward a rational classification of climate. Geogr. Rev. 38:55–94.

U.S. Department of Commerce.
1976. Climatological data, Tennessee annual summary. 81:13, 12 p.

U.S. Forest Service.
1929. Volume, yield, and stand tables for second-growth southern pines. U.S. Dep. Agric., Misc. Pub. No. 50. 202 p. (Slightly revised 1976.)

Vimmerstedt, J. P.
1962. Southern Appalachian white pine plantations: Site, volume, and yield. U.S. Dep. Agric. For. Serv., Stn. Pap. 149. Southeast. For. Exp. Stn., Asheville, N. C. 13 p.

Wade, G. L.
1977. Dry phase vegetation of the uplands of the Cumberland Plateau of Tennessee. M. S. Thesis, Univ. Tenn., Knoxville. 116 p.

Wertz, W. A., and J. F. Arnold.
1975. Land stratification for land-use planning. *In* B. Bernier and C. H. Winget (ed.), Forest Soils and Forest Land Management, p. 617–629. Les Presses de l'Université Laval, Quebec.

Wilson, C. W., Jr., and R. G. Stearns.
1958. Structure of the Cumberland Plateau, Tennessee. Bull. Geol. Soc. Am. 69:1283–1296.

Winters, R. K., and J. G. Osborne.
1935. Growth and yield of second-growth red gum in fully stocked stands on alluvial lands in the South. U.S. Dep. Agric. For. Serv., Occas. Pap. 54. South. For. Exp. Stn., New Orleans, La. 12 p.

APPENDIX

County Soil Surveys Available for the Mid-Cumberland Plateau[3]

Elder, J. A., E. K. Yates, I. B. Epley, and L. E. Odum.
1958. Soil survey of Marion County, Tennessee. U.S. Dep. Agric., Soil Conserv. Serv. Series 1950, No. 2, 88 p. + maps.

Fox, C. J., T. E. Beesley, R. G. Leighty, E. Lusk, A. B. Harmon, Jr., H. C. Smith, Jr., C. Methvin, and R. L. Flowers.
1958. Soil survey of Franklin County, Tennessee. U.S. Dep. Agric., Soil Conserv. Serv. Series 1949, No. 8, 91 p. + maps.

Fussell, K. E., and E. A. Perry.
1959. Soil survey of Marshall County, Alabama. U. S. Dep. Agric., Soil Conserv. Serv. Series 1956, No. 2. 61 p. + maps.

*Jackson, G. T., S. R. Bacon, J. F. Brasfield, D. B. Freeman, and I. D. Persinger.
1967. Soil survey of Warren County, Tennessee. U.S. Dep. Agric., Soil Conserv. Serv. 79 p. + maps.

*Jackson, G. T., S. R. Bacon, B. C. Cox, and C. R. Gass.
1963. Soil survey of Putnam County, Tennessee. U.S. Dep. Agric., Soil Conserv. Serv. Series 1960, No. 7. 114 p. + maps.

Love, T. R., L. D. Williams, W. H. Proffitt, I. B. Epley, and J. Elder.
1959. Soil survey of Coffee County, Tennessee. U.S. Dep. Agric., Soil Conserv. Serv. Series 1956, No. 5, 112 p. + maps.

*Moore, R. K., J. F. Campbell, and W. C. Moffitt.
1981. Soil survey of White and Van Buren Counties, Tennessee. U.S. Dep. Agric., Soil Conserv. Serv. 86 p. + maps.

*Soil Conservation Service.
(In press) Soil survey of Fentress and Pickett Counties, Tennessee.

*Soil Conservation Service.
(In press) Soil survey of Hamilton County, Tennessee.

Swenson, G. A., H. Sherard, A. Baxter, R. Farnham, H. J. Wesson, and B. E. Young.
1958. Soil survey of Madison County, Alabama. U.S. Dep. Agric., Soil Conserv. Serv. Series 1947, No. 3. 101 p. + maps.

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[3] Asterisk denotes survey that contains a section on woodland suitability.

METRIC EQUIVALENTS

1 inch = 2.54 centimeters (exactly)
1 foot = 0.3048 meter (exactly)
1 acre = 0.4047 hectare
1 square foot/acre = 0.2296 square meter/hectare
1 cubic foot/acre = 0.06997 cubic meter/hectare
1 mile = 1.6093 kilometers
1 square mile = 2.5900 square kilometers
°C = (°F − 32)/1.8

SMALLEY, GLENDON W.
1982. Classification and evaluation of forest sites on the Mid-Cumberland Plateau. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. S0-38. South. For. Exp. Stn., New Orleans, La. 58 p.

Presents a comprehensive forest site classification system for the central portion of the Cumberland Plateau in northeast Alabama, and east-central Tennessee. The system is based on physiography, geology, soils, topography, and vegetation.

Additional keywords: Site index, mean annual increment, soil properties, pines, hardwoods.

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Computer Can Choose Sowing Strategies for Containerized Seedlings

William D. Pepper and W. Douglas Hodge

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Computer Can Choose Sowing Strategies for Containerized Seedlings

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INTRODUCTION

A crucial problem for nursery managers in growing containerized seedlings results from blank containers. If the overall germination and survival rate is low and a single seed is planted in each container, the number of blank containers will be high, and the cost of carrying these blanks may be unacceptable. Because of the high cost of growing containerized seedlings, efficient methods are needed to deal with the problem caused by blank containers.

The proportion of blank containers can be reduced by planting more than one seed in some or all containers. However, this remedial action requires the sowing of additional seeds and will result in multiple excess seedlings for some containers, which must be thinned and discarded or replanted.

Thus, the nursery manager needs a sowing strategy hat deals effectively with the problem of blanks. But he strategy must not impose a severe penalty in terms f additional seed-related and thinning costs.

In this paper we present an interactive computer program (CONSOW) that enables the user to choose n optimal sowing strategy. The strategy is optimal in he sense that it minimizes a penalty function which eflects the cost of carrying blank containers and costs of remedial actions taken to combat the problem of lanks.

CONSOW, written in the programming language BASIC, was developed on a Hewlett-Packard 9830A microcomputer. The 9830A version is one of many ersions of BASIC that exist today, and most are machine-dependent. Therefore, some modifications might be necessary to run CONSOW on other computers.

CONSOW was also written in ANS FORTRAN IV—1977. This program is not interactive, as is the BASIC version, but the input variables are entered on cards and the job is run in the batch mode. Both programs are punched on cards and copies can be acquired from the Southern Forest Experiment Station, Biometrics Branch, T-10210 U.S. Postal Services Building, 701 Loyola Avenue, New Orleans, Louisiana 70113.

SOWING STRATEGIES

Choosing a sowing strategy amounts to specifying values $0 \leq X_j \leq 1$, $\Sigma_j X_j = 1$ ($j = 1, 2, \ldots, n$) where X_j = fraction of total number of containers in which j seeds are planted. In practical container operations the number of seeds does not generally exceed three, so it is only necessary to choose values for X_1, X_2, and X_3. In practice, containers may be grouped in trays or blocks of 70 to several hundred individuals, in which case X_j refers to the fraction of trays or blocks in which each container receives j seeds.

In this paper, sowing is presumed to be accomplished by a widely used technique employing a vacuum-operated seeder (Carlson, 1979). This type of seeder uses a vacuum to hold single seeds over holes in a template. When the vacuum is released, the seeds drop into cavities beneath the holes. A sowing strategy is accomplished by making j passes over $(M)(X_j)$ trays, where M = total number of trays and $j = 1, 2, 3$.

The program provides two sowing options for producing a given number of seedlings: Option 1. Blank containers are not replanted, but excess seedlings are thinned. Option 2. Use a sowing strategy for which the predicted number of blanks does not exceed the predicted number of excess seedlings. Remove enough excess seedlings to replant blanks, insuring that each cell is occupied, and thin the remaining excess seedlings.

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MATHEMATICAL BASIS OF THE PROGRAM

Explanation of Symbols

The key quantities in a sowing strategy are total number of containers (N), total number of seeds (S), predicted number of plantable seedlings before thinning ($\hat{Z}$), predicted number of plantable seedlings after each occupied cell is thinned to one seedling ($\hat{Y}$), predicted number of excess seedlings ($\hat{E}$), and predicted number of blank containers ($\hat{B}$). These quantities are computed as follows in terms of germination and survival rates and sowing frequencies:

[1] $S = N(X_1 + 2X_2 + 3X_3),\ \bar{S} = S/N,$

[2] $\hat{Z} = N(\hat{P}_{11} X_1 + (\hat{P}_{12} + 2\hat{P}_{22})X_2 + (\hat{P}_{13} + 2\hat{P}_{23} + 3\hat{P}_{33})X_3),\ \bar{\hat{Z}} = \hat{Z}/N,$

[3] $\hat{Y} = N(\hat{P}_{11} X_1 + (\hat{P}_{12} + \hat{P}_{22})X_2 + (\hat{P}_{13} + \hat{P}_{23} + \hat{P}_{33})X_3),\ \bar{\hat{Y}} = \hat{Y}/N,$

[4] $\hat{E} = N(\hat{P}_{22} X_2 + (\hat{P}_{23} + 2\hat{P}_{33})X_3),\ \bar{\hat{E}} = \hat{E}/N,$

[5] $\hat{B} = N(\hat{P}_{01} X_1 + \hat{P}_{02} X_2 + \hat{P}_{03} X_3),\ \bar{\hat{B}} = \hat{B}/N,$

where

$\hat{P}_{ij}$ = estimated probability of producing i plantable seedlings given that j seeds were planted ($i = 0, 1, 2, 3;\ j = 1, 2, 3;\ i \leqslant j$).

These probabilities may be estimated with the binomial formula $\hat{P}_{ij} = \frac{j!}{(j-i)!i!} (\hat{p})^{i}(1-\hat{p})^{j-i}\ i = 0, 1, 2, \ldots, j,$ where $\hat{p}$ = estimated germination and survival rate. In practice, this estimate will often represent an overall average germination and survival rate for a composite of seedlots. Naturally, the reliability of the estimate is influenced by the amount of variation within and among seedlots, but will usually not be quantified because of the lack of estimates for these variances. For a discussion of the validity of using this model to compute the $\hat{P}_{ij}$'s see Pepper and Barnett (1981a).

Cost Components of a Penalty Function

It is neither realistic nor necessary to identify all costs that might occur in the production of a container-grown seedling. Rather, a function is defined to reflect the penalty when blanks occur and remedial actions are taken.

As a point of departure, consider the extreme case of perfect seed and seedling performance with 100 percent germination and survival. In this case, a single seed is planted in N cells and N seedlings are produced; no thinning is necessary and no blanks occur. Thus, the seed-related cost for the first N seeds is not regarded as a penalty. But in reality, blanks do occur and the sowing strategy chosen aims to reduce blanks. The additional number of seed required is S − N and the additional cost is $(C_{sd} + C_{sw})(S - N)$ where

C_{sd} = cost per seed and
C_{sw} = cost per seed for sowing.

The cost of carrying blanks and/or replanting blanks is (C_b) (number of blanks carried) + (C_r) (number of blanks replanted) where

C_b = cost per cell for carrying blanks and
C_r = cost per cell for removing the required number of excess seedlings and replanting blanks.

The cost for thinning excess seedlings is (C_t) (number of excess seedlings) where

C_t = cost per seedling for thinning seedlings not used for replanting blanks.

It is assumed that the cost of sowing is the same for each seed. This assumption seems logical since the seeder must make a pass over the tray of cells for each seed planted per cell. The cost for thinning is assumed to be the same for each seedling. The cost of replanting a blank cell consists of the cost of removing an excess seedling from another cell and transplanting it to the blank cell. The mortality of transplanted seedlings is assumed to be negligible. The cost of carrying a blank cell is defined as the cost of the container plus the cost of the medium. Container costs vary according to the type and the number of times that they can be reused. For a discussion of the above assumptions see Pepper and Barnett (1981b).

The sum of the independent contributions of the components described above is the total penalty, including the cost of blanks and the cost of remedial actions to reduce blanks. CONSOW enables the user to choose a strategy (X_1, X_2, X_3) to minimize the predicted total penalty.

The formula for calculating predicted penalty depends on the sowing option used. For Option 1 the predicted penalty is

[6] $\hat{P}_c = (C_{sd} + C_{sw})(S - N) + C_b\hat{B} + C_t\hat{E}.$

For Option 2 the predicted penalty is

[7] $\hat{P}_c = (C_{sd} + C_{sw})(S - N) + C_r\hat{B} + C_t(\hat{E} - \hat{B}).$

Constraints on Sowing Frequencies

The first step in formulating a container sowing problem specifies the required number of seedlings (Y_R) to be produced and the number (N) of containers. In the case of Option 1, X_1, X_2, X_3 will be chosen to minimize the predicted penalty subject to the constraint that the predicted number of seedlings is not less than the required number. Mathematically, the problem is to minimize

$\hat{P}_c = (N)(C_1X_1 + C_2X_2 + C_3X_3)$, subject to

[8] $N(\hat{P}_{11}X_1 + (\hat{P}_{12} + \hat{P}_{22})X_2 + (\hat{P}_{13} + \hat{P}_{23} + \hat{P}_{33})X_3) \geqslant Y_R$
$X_1 + X_2 + X_3 = 1$
$X_1, X_2, X_3 \geqslant 0$

where

$$C_1 = C_b\hat{P}_{01}$$
$$C_2 = C_{sd} + C_{sw} + C_b\hat{P}_{02} + C_t\hat{P}_{22},$$

and

$$C_3 = 2(C_{sd} + C_{sw}) + C_b\hat{P}_{03} + (\hat{P}_{23} + 2\hat{P}_{33})C_t.$$

Dividing the first constraint by N yields the required number of seedlings per cell ($\overline{Y}_R$) on the right hand side of the inequality. This quantity is to be distinguished from $\hat{\overline{Y}}$ defined in [3] above.

With Option 2, the optimization problem is to minimize the predicted penalty subject to the constraint that the predicted number of blanks does not exceed the predicted number of excess seedlings. Mathematically, we minimize

$$\hat{P}_c = (N)(K_1X_1 + K_2X_2 + K_3X_3)$$

subject to

$$[9] \quad N\{-\hat{P}_{01}X_1 + (\hat{P}_{22} - \hat{P}_{02})X_2 + (\hat{P}_{23} + 2\hat{P}_{33} - \hat{P}_{03})X_3\} \geqslant 0$$
$$X_1 + X_2 + X_3 = 1$$
$$X_1, X_2, X_3 \geqslant 0$$

where

$$K_1 = (C_r - C_t)\hat{P}_{01}$$
$$K_2 = C_{sd} + C_{sw} + (C_r - C_t)\hat{P}_{02} + C_t\hat{P}_{22}$$
$$K_3 = 2(C_{sd} + C_{sw}) + (C_r - C_t)\hat{P}_{03} + C_t(\hat{P}_{23} + 2\hat{P}_{33}).$$

Since the penalty function and constraints are linear in the X's and the constraints define a convex set of admissable solutions, linear programming can be used to determine the optimal solution. Solutions at corners or vertices of the set of admissable solutions are termed extreme points in linear programming problems and are known to be the only candidates for optimality. Since the number of extreme point solutions is small, the optimal one can be found by inspecting the value of the penalty function at each of these.

In linear programming problems of greater complexity with large numbers of extreme points, iterative procedures, usually computer-oriented, lead to optimal solutions without examining each extreme point in the set of admissable points.

USING THE PROGRAM

User-Supplied Information

CONSOW prompts the user for values of 13 variables that deal with costs, alternatives for program changes, sowing options, and rates of survival. The first variable needed in the program is the option variable. A value of 1 (transplanting-no) or 2 (transplanting-yes) is entered for Option 1 or 2 respectively.

The next required variable is the germination and survival rate (p), which is entered as a decimal fraction between 0.00 and 1.00.

In Option 1, four different costs are entered. They are the cost per thousand seeds (C_{sd}), cost per thousand seeds for sowing (C_{sw}), cost per thousand seedlings for thinning seedlings not used for replanting blanks (C_t), and the cost per thousand cells for carrying blank cells (C_b).

In Option 2, three of the costs are identical: Cost per thousand seeds, cost per thousand seeds for sowing, and cost per thousand seedlings for thinning seedlings not used for replanting blanks. The only difference is that the cost of carrying blank cells is replaced by the cost per thousand seedlings for removing the required number of excess seedlings and replanting blank cells (C_r). In Option 1, blank cells are not replanted.

The required number of seedlings per container ($\overline{Y}_R$), found by dividing the required number of seedlings by the total number of containers available, must be entered. This number is to be distinguished from the predicted number of seedlings ($\hat{\overline{Y}}$) per cell.

The remaining variables deal with altering the user-supplied variables. There are a series of 5 questions to be answered yes or no. The first question deals with whether or not changes will be made. If not, the program will end. Any combination of the remaining four independent alternatives is possible. The alternatives are: (1) begin a new page, (2) change the germination and survival rate, (3) change the cost coefficients and (4) change the required number of seedlings per container in Option 1.

Operations Performed by the Program

CONSOW is divided into two sections, a section for Option 1 and a section for Option 2. The operations in each section are similar; only the sets of cost coefficients are different, and the predicted number of seedlings is calculated after thinning for Option 1 and before thinning for Option 2. The operations can be identified by comment statements in the listing of the program in Appendix 1.

The program performs the following operations:

(1) Prompts the user for a choice of options and prints the appropriate headings.

(2) Given the germination and survival rate, the binomial probabilities, needed in the constraints and prediction equations, are calculated and summed.

(3) Prompts the user for the cost of seeds, the cost of sowing, and the cost of thinning excess seedlings not used for replanting blanks.

(4) For Option 1, prompts user for required number of seedlings per container to be produced and for the cost per thousand cells of carrying blank cells. For Option 2, the user supplies the cost per thousand seedlings for removing the required number of excess seed-

lings and replanting blank cells. The required number of seedlings per container is set to one in Option 2 because all of the blank cells are replanted with the thinned seedlings.

(5) Determines all extreme point solutions, *i.e.* sets of values for X_1, X_2, and X_3 satisfying specified constraints.

(6) Determines the expected number of excess seedlings per cell, the predicted number of plantable seedlings per cell after thinning for Option 1 and before thinning for Option 2, and the average number of seeds per cell.

(7) Calculates cost coefficients for the penalty function, the penalty per thousand cells in dollars, and the penalty per thousand seedlings in dollars. The final tables are printed for the option selected.

(8) Alternatives are given to end the program or to analyse a new problem with new linear programming model parameters.

An Example

Suppose Option 1 is used in an operation requiring 300,000 seedlings. Assume that $p = 0.7$ and cost values are $C_{sd} = \$1.70$ per 1,000 seeds, $C_{sw} = \$4.04$ per 1,000 seeds, $C_t = \$8.37$ per 1,000 seedlings[1] and $C_b = \$13.00$ per 1,000 cells[2]. The decision is made to use $N = 375{,}000$ containers for a mean yield of 300,000/375,000 = 0.8 seedlings per container.

Appendix 2 provides a computer printout containing an exhaustive list of four extreme point solutions for this problem. For each extreme point solution penalty per thousand containers is computed

$$\hat{P}_c = C_1X_1 + C_2X_2 + C_3X_3,$$

where C_j's are calculated as shown in equation [8]. Penalty per thousand seedlings produced is $\hat{P}_s = \hat{P}_c/\hat{Y}$. By computing penalty values at each extreme point we find that $(X_1, X_2, X_3) = (0.52, 0.48, 0.00)$ produces the smallest value. The theory of linear programming assures us that this choice of X's produces the absolute minimum penalty for the given set of constraints.

Suppose Option 2 is used in an operation requiring a yield of 375,000 seedlings with 375,000 containers. This obviously implies $\bar{Y}_R = 1$. Assume that cost values are the same as above except that C_b is replaced by $C_r / = \$16.79$ per thousand cells[2]. Appendix 2 shows an exhaustive list of four extreme point solutions for p = 0.7 and $\bar{Y}_R = 1$. The optimal solution is $(X_1, X_2, X_3) = (0.57, 0.43, 0.00)$. For Option 2, the total number of plantable seedlings per cell ($\hat{Z}$) includes excess seedlings which are used to replant blanks.

The example above shows how an optimal sowing strategy is found for a specified germination and survival rate and a given set of costs. The program can also be used to study the effects of changing these parameters. For example, a user might wish to see how optimality changes for a given set of costs as the germination and survival rate is improved, or how optimality and penalty change as costs change.

REFERENCES

Carlson, L.W.
1979. Guidelines for rearing containerized conifer seedlings in the Prairie Provinces. Information Report NOR-X-214, 62 p. Canadian Forestry Service, Northern Forest Research Centre, Edmonton, Alberta.

Hadley, G.
1961. Linear algebra. Addison-Wesley Publishing Co., Inc., Reading, MA 290 p.

Hadley, G.
1962. Linear programming. Addison-Wesley Publishing Co., Inc., Reading, MA 520 p.

Pepper, W.D. and J.P. Barnett.
1981a. Predicting seed germination and seedling establishment in containers. Can. J. For. Res. 11(3):677–681.

Pepper, W.D. and J.P. Barnett.
1981b. Choosing sowing strategies for containerized seedling operations. Can. J. For. Res. 11(3):682–688.

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[1] These estimates were provided by the Stuart Containerized Seedling Project, Kisatchie National Forest, Pollock, LA. This project is administered by the Range, Timber and Wildlife Division, National Forest System, Region 8, Atlanta, GA.

[2] These estimates were provided by Research Work Unit SO-1102, Southern Forest Experiment Station, Alexandria, LA.

APPENDIX 1—Listing of Program CONSOW

```
10 REM --PROGRAM  CONSOW--
20 REM
30 REM    FOR A GIVEN CONTAINER SOWING OPERATION, THIS PROGRAM
40 REM DETERMINES A SET OF CONTAINER SOWING STRATEGIES WHICH
50 REM SATISFY CERTAIN SPECIFIED CONSTRAINTS.  THE SOWING
60 REM STRATEGY WITH THE SMALLEST PENALTY PER CELL OR PENALTY
70 REM PER SEEDLING IS OPTIMUM IN THE SENSE THAT IT DOES THE
80 REM MOST EFFICIENT JOB OF DEALING WITH THE PROBLEM OF BLANK
90 REM CELLS.
100 REM    THERE ARE TWO OPTIONS AVAILABLE TO THE USER.  SOWING
110 REM STRATEGIES FOR OPTION 1 ARE EXPECTED TO PRODUCE THE
120 REM REQUIRED NUMBER OF SEEDLINGS WITHOUT REPLANTING BLANK
130 REM CELLS.  EXCESS SEEDLINGS ARE THINNED AND DISCARDED.
140 REM OPTION 2 SOWING STRATEGIES ARE EXPECTED TO PRODUCE THE
150 REM REQUIRED NUMBER OF SEEDLINGS BY REPLANTING BLANK CELLS
160 REM WITH EXCESS SEEDLINGS.  EACH SOWING STRATEGY IS REQUIRED
170 REM TO PRODUCE A SUFFICIENT NUMBER OF EXCESS SEEDLINGS TO
180 REM REPLANT ALL BLANK CELLS.  ANY EXCESS SEEDLINGS NOT USED
190 REM FOR REPLANTING BLANK CELLS ARE THINNED AND DISCARDED.
200 REM     THE PROGRAM WILL PROMPT THE USER FOR INFORMATION
210 REM REGARDING THE COST COMPONENTS, THE ESTIMATED GERMINATION
220 REM AND SURVIVAL RATES, AND THE REQUIRED NUMBER OF SEEDLINGS
230 REM PER CONTAINER.  THE REQUIRED NUMBER OF SEEDLINGS PER
240 REM CONTAINER IS DETERMINED BY DIVIDING THE REQUIRED NUMBER
250 REM OF SEEDLINGS BY THE TOTAL NUMBER OF AVAILABLE CONTAINERS.
260 REM    THE FOLLOWING VARIABLE NAMES APPEAR IN THE COLUMN
270 REM HEADINGS IN TABLES PRODUCED BY THE PROGRAM:
280 REM
290 REM     P - ESTIMATED GERMINATION AND SURVIVAL RATE
300 REM
310 REM     YBAR - REQUIRED NUMBER OF SEEDLINGS PER CELL
320 REM
330 REM     X1 - FRACTION OF TOTAL NUMBER OF CELLS RECEIVING
340 REM          1 SEED
350 REM
360 REM     X2 - FRACTION OF TOTAL NUMBER OF CELLS RECEIVING
370 REM          2 SEEDS
380 REM
390 REM     X3 - FRACTION OF TOTAL NUMBER OF CELLS RECEIVING
400 REM          3 SEEDS
410 REM
420 REM     SBAR - AVERAGE NUMBER OF SEEDS PER CELL
430 REM
440 REM     YHAT - PREDICTED NUMBER OF PLANTABLE SEEDLINGS
450 REM            AFTER EXCESS SEEDLINGS HAVE BEEN
460 REM            THINNED AND REPLANTED OR DISCARDED
470 REM
480 REM     ZHAT - TOTAL NUMBER OF PLANTABLE SEEDLINGS
490 REM            BEFORE THINNING
500 REM
510 REM     EHAT - PREDICTED NUMBER OF EXCESS SEEDLINGS
520 REM
530 REM     PENALTY - ECONOMIC INDEX OF EFFICIENCY
540 REM
550 REM
560 IF A$="N" THEN 850
570 DISP "OPTION 1 OR OPTION 2?  1 OR 2";
```

```
580 INPUT Y
590 PRINT
600 PRINT
610 REM *** PRINT HEADINGS ***
620 IF Y=2 THEN 650
630 PRINT TAB8" OPTION ONE SOWING STRATEGIES"
640 GOTO 660
650 PRINT TAB8" OPTION TWO SOWING STRATEGIES"
660 PRINT
670 PRINT
680 IF Y=2 THEN 740
690 WRITE (15,710)" ";
700 WRITE (15,720)
710 FORMAT 16X,"EXTREME POINT SOLUTIONS",10X,"YHAT",3X,"EHAT"
720 FORMAT 5X,"PENALTY"
730 GOTO 780
740 WRITE (15,760)" ";
750 WRITE (15,770)
760 FORMAT 16X,"EXTREME POINT SOLUTIONS",10X,"ZHAT", 3X,"EHAT"
770 FORMAT 5X,"PENALTY"
780 WRITE (15,790)" "
790 FORMAT 49X,"PER",4X,"PER",4X,"PER",5X,"PER"
800 WRITE (15,820)" ";
810 WRITE (15,830)" ";
820 FORMAT 8X,"P",3X,"YBAR",4X,"X1",5X,"X2",5X,"X3",5X,"SBAR"
830 FORMAT 4X,"CELL",2X,"CELL",3X,"CELL",4X,"M SDLGS"
840 PRINT
850 IF B$="N" THEN 1010
860 REM  *** FIND THE GERMINATION AND SURVIVAL RATE ***
870 DISP "ENTER ESTIMATED GERMINATION AND"
880 WAIT 3000
890 DISP "SURVIVAL RATE";
900 INPUT P
910 REM  *** CALCULATE BINOMIAL PROBABILITIES ***
920 P1=1-P
930 P2=P
940 P3=(1-P)^2
950 P4=2*P*(1-P)
960 P5=(1-P)^3
970 P6=3*P*(1-P)^2
980 P7=P*P
990 P8=3*P*P*(1-P)
1000 P9=P^3
1010 IF C$="N" THEN 1110
1020 REM *** DETERMINE THE COST COEFFICIENTS ***
1030 DISP "ENTER COST PER 1000 SEEDS";
1040 INPUT S1
1050 DISP "ENTER COST / M SEEDS FOR SOWING";
1060 INPUT S2
1070 DISP "ENTER COST / M SEEDLINGS FOR"
1080 WAIT 3000
1090 DISP "THINNING SEEDLINGS NOT USED";
1100 INPUT T
1110 REM *** BEGINNING OF OPTION 1 SOWING STRATEGY ***
1120 IF Y=2 THEN 2250
1130 IF A$="Y" THEN 1150
1140 IF D$="N" THEN 1250
```

```
1150 REM *** DETERMINE THE NUMBER OF SEEDLINGS PER CELL ***
1160 DISP "ENTER REQUIRED NUMBER"
1170 WAIT 3000
1180 DISP "OF SEEDLINGS PER CONTAINER";
1190 INPUT A4
1200 REM *** CALCULATE PROPORTION CONSTRAINT COEFFICIENTS ***
1210 A1=P2
1220 A2=P4+P7
1230 A3=P6+P8+P9
1240 REM *** CALCULATE THE SEED PROPORTIONS ***
1250 D1=A3-A2
1260 D2=A3-A1
1270 D3=A2-A1
1280 X2=(A3/D1)-(A4/D1)
1290 X3=(-A2/D1)+(A4/D1)
1300 Y1=(A3/D2)-(A4/D2)
1310 Y3=(-A1/D2)+(A4/D2)
1320 Z1=(A2/D3)-(A4/D3)
1330 Z2=(-A1/D3)+(A4/D3)
1340 IF A$="Y" THEN 1360
1350 IF C$="N" THEN 1400
1360 DISP "ENTER COST PER 1000 CELLS"
1370 WAIT 3000
1380 DISP "FOR CARRYING BLANKS";
1390 INPUT B
1400 X2=X2+0.000001
1410 X3=X3+0.000001
1420 Y1=Y1+0.000001
1430 Y3=Y3+0.000001
1440 Z1=Z1+0.000001
 450 Z2=Z2+0.000001
 460 REM *** CALCULATE PENALTY COST COEFFICIENTS ***
 470 C1=B*P1
1480 C2=S1+S2+B*P3+T*P7
1490 C3=2*(S1+S2)+B*P5+T*P8+2*T*P9
1500 REM *** CALCULATE THE EXPECTED NUMBER OF EXCESS
1510 REM                 SEEDLINGS PER CELL ***
1520 E1=P7
1530 B1=P3
1540 E2=P8+2*P9
1550 B2=P5
1560 E3=P7*X2+P8*X3+2*P9*X3
1570 B3=P3*X2+P5*X3
1580 E4=P8*Y3+2*P9*Y3
1590 B4=P1*Y1+P5*Y3
1600 E5=P7*Z2
1610 B5=P1*Z1+P3*Z2
1620 REM *** CALCULATE THE PENALTY PER THOUSAND CELLS
1630 REM                      IN DOLLARS ***
1 40 W1=C2
1 50 W2=C3
1660 W3=C2*X2+C3*X3
1670 W4=C1*Y1+C3*Y3
1680 W5=C1*Z1+C2*Z2
1 90 REM *** CALCULATE THE PREDICTED NUMBER OF PLANTABLE
1700 REM             SEEDLINGS PER CELL AFTER THINNING ***
1710 T1=A2
```

```
1720 T2=A3
1730 T3=A2*X2+A3*X3
1740 T3=T3+0.000001
1750 T4=A1*Y1+A3*Y3
1760 T4=T4+0.000001
1770 T5=A1*Z1+A2*Z2
1780 T5=T5+0.000001
1790 REM *** CALCULATE NUMBER OF SEEDS PER CELL ***
1800 Q1=2
1810 Q2=3
1820 Q3=2*X2+3*X3
1830 Q4=Y1+3*Y3
1840 Q5=Z1+2*Z2
1850 REM *** CALCULATE PENALTY PER THOUSAND SEEDLINGS
1860 REM                  IN DOLLARS ***
1870 V1=W1/T1
1880 V2=W2/T2
1890 V3=W3/T3
1900 V4=W4/T4
1910 V5=W5/T5
1920 REM *** PRINT THE RESULTS ***
1930 PRINT
1940 IF T1<A4 THEN 2000
1950 WRITE (15,1970)P,A4;
1960 WRITE (15,1980)Q1,T1,E1,W1,V1;
1970 FORMAT 6X,F4.1,1X,F5.2,3X,"0.00",3X,"1.00",3X,"0.00"
1980 FORMAT 3X,F5.2,3X,F5.2,2X,F5.2,2X,F6.2,2X,F6.2
1990 PRINT
2000 IF T2<A4 THEN 2060
2010 WRITE (15,2030)P,A4;
2020 WRITE (15,2040)Q2,T2,E2,W2,V2;
2030 FORMAT 6X,F4.1,1X,F5.2,3X,"0.00",3X,"0.00",3X,"1.00"
2040 FORMAT 3X,F5.2,3X,F5.2,2X,F5.2,2X,F6.2,2X,F6.2
2050 PRINT
2060 IF T3<A4 OR X2<0.0001 OR X3<0.0001 THEN 2120
2070 WRITE (15,2090)P,A4,X2,X3;
2080 WRITE (15,2100)Q3,T3,E3,W3,V3;
2090 FORMAT 6X,F4.1,1X,F5.2,3X,"0.00",2X,F5.2,2X,F5.2
2100 FORMAT 3X,F5.2,3X,F5.2,2X,F5.2,2X,F6.2,2X,F6.2
2110 PRINT
2120 IF T4<A4 OR Y1<0.0001 OR Y3<0.0001 THEN 2180
2130 WRITE (15,2150)P,A4,Y1,Y3;
2140 WRITE (15,2160)Q4,T4,E4,W4,V4;
2150 FORMAT 6X,F4.1,1X,F5.2,2X,F5.2,3X,"0.00",2X,F5.2
2160 FORMAT 3X,F5.2,3X,F5.2,2X,F5.2,2X,F6.2,2X,F6.2
2170 PRINT
2180 IF T5<A4 OR Z1<0.0001 OR Z2<0.0001 THEN 2230
2190 WRITE (15,2210)P,A4,Z1,Z2;
2200 WRITE (15,2220)Q5,T5,E5,W5,V5;
2210 FORMAT 6X,F4.1,1X,F5.2,2X,F5.2,2X,F5.2,3X,"0.00"
2220 FORMAT 3X,F5.2,3X,F5.2,2X,F5.2,2X,F6.2,2X,F6.2
2230 PRINT
2240 GOTO 3360
2250 REM *** OPTION 2 SOWING STRATEGY ***
2260 A1=P2
2270 A2=P4+2*P7
2280 A3=P6+2*P8+3*P9
```

```
2290 A4=1
2300 B1=-P1
2310 B2=P7-P3
2320 B3=P8+(2*P9)-P5
2330 IF A$="Y" THEN 2350
2340 IF C$="N" THEN 2440
2350 DISP "ENTER COST PER 1000 SEEDLINGS"
2360 WAIT 3000
2370 DISP "FOR REMOVING THE REQUIRED NUMBER"
2380 WAIT 3000
2390 DISP "OF EXCESS SEEDLINGS AND"
2400 WAIT 3000
2410 DISP "REPLANTING BLANKS";
2420 INPUT R
2430 REM *** CALCULATE PENALTY COST COEFFICIENTS ***
2440 C1=(R-T)*P1
2450 C2=S1+S2+(R-T)*P3+T*P7
2460 C3=2*(S1+S2)+(R-T)*P5+T*P8+2*T*P9
2470 D1=B3-B2
2480 D2=B3-B1
2490 D3=B2-B1
2500 REM *** CALCULATE SEED PROPORTIONS ***
2510 X2=B3/D1
2520 X2=X2+0.000001
2530 X3=-B2/D1
2540 X3=X3+0.000001
2550 Y1=B3/D2
2560 Y1=Y1+0.000001
2570 Y3=-B1/D2
2580 Y3=Y3+0.000001
590 Z1=B2/D3
600 Z1=Z1+0.000001
610 Z2=-B1/D3
2620 Z2=Z2+0.000001
2630 REM *** CALCULATE EXCESS SEEDLINGS ***
640 E1=P7
2650 O1=P3
2660 E2=P8+2*P9
2670 O2=P5
2680 E3=P7*X2+P8*X3+2*P9*X3
2690 O3=P3*X2+P5*X3
2700 E4=P8*Y3+2*P9*Y3
2710 O4=P1*Y1+P5*Y3
2720 E5=P7*Z2
2730 O5=P1*Z1+P3*Z2
2740 REM *** CALCULATE THE PENALTY PER THOUSAND CELLS
2750 REM                    IN DOLLARS ***
2760 W1=C2
2770 W2=C3
2780 W3=C2*X2+C3*X3
2790 W4=C1*Y1+C3*Y3
2800 W5=C1*Z1+C2*Z2
2810 REM *** CALCULATE NUMBER OF SEEDS PER CELL ***
2820 Q1=2
2830 Q2=3
2840 Q3=2*X2+3*X3
2850 Q4=Y1+3*Y3
```

```
2860 Q5=Z1+2*Z2
2870 REM *** CALCULATE THE PREDICTED NUMBER OF PLANTABLE
2880 REM       SEEDLINGS PER CELL AFTER THINNING ***
2890 T1=A2
2900 T2=A3
2910 T3=A2*X2+A3*X3
2920 T3=T3+0.000001
2930 T4=A1*Y1+A3*Y3
2940 T4=T4+0.000001
2950 T5=A1*Z1+A2*Z2
2960 T5=T5+0.000001
2970 REM *** CALCULATE THE PENALTY PER THOUSAND
2980 REM          SEEDLINGS IN DOLLARS ***
2990 V1=W1/T1
3000 V2=W2/T2
3010 V3=W3/T3
3020 V4=W4/T4
3030 V5=W5/T5
3040 PRINT
3050 REM *** PRINT TABLES ***
3060 IF T1<1 OR E1<O1 THEN 3120
3070 WRITE (15,3090)P,A4;
3080 WRITE (15,3100)Q1,T1,E1,W1,V1
3090 FORMAT 6X,F4.1,1X,F5.2,3X,"0.00",3X,"1.00",3X,"0.00"
3100 FORMAT 3X,F5.2,3X,F5.2,2X,F5.2,2X,F6.2,2X,F6.2
3110 PRINT
3120 IF T2<1 OR E2<O2 THEN 3180
3130 WRITE (15,3150)P,A4;
3140 WRITE (15,3160)Q2,T2,E2,W2,V2;
3150 FORMAT 6X,F4.1,1X,F5.2,3X,"0.00",3X,"0.00",3X,"1.00"
3160 FORMAT 3X,F5.2,3X,F5.2,2X,F5.2,2X,F6.2,2X,F6.2
3170 PRINT
3180 IF T3<1 OR E3<O3 OR X2<=0.0001 OR X3<=0.0001 THEN 3240
3190 WRITE (15,3210)P,A4,X2,X3;
3200 WRITE (15,3220)Q3,T3,E3,W3,V3;
3210 FORMAT 6X,F4.1,1X,F5.2,3X,"0.00",2X,F5.2,2X,F5.2
3220 FORMAT 3X,F5.2,3X,F5.2,2X,F5.2,2X,F6.2,2X,F6.2
3230 PRINT
3240 IF T4<1 OR E4<O4 OR Y1<=0.0001 OR Y3<=0.0001 THEN 3300
3250 WRITE (15,3270)P,A4,Y1,Y3;
3260 WRITE (15,3280)Q4,T4,E4,W4,V4;
3270 FORMAT 6X,F4.1,1X,F5.2,2X,F5.2,3X,"0.00",2X,F5.2
3280 FORMAT 3X,F5.2,3X,F5.2,2X,F5.2,2X,F6.2,2X,F6.2
3290 PRINT
3300 IF T5<1 OR E5<O5 OR Z1<=0.0001 OR Z2<=0.0001 THEN 3360
3310 WRITE (15,3330)P,A4,Z1,Z2;
3320 WRITE (15,3340)Q5,T5,E5,W5,V5;
3330 FORMAT 6X,F4.1,1X,F5.2,2X,F5.2,2X,F5.2,3X,"0.00"
3340 FORMAT 3X,F5.2,3X,F5.2,2X,F5.2,2X,F6.2,2X,F6.2
3350 PRINT
3360 DISP "TO ANSWER FOLLOWING QUESTIONS "
3370 WAIT 3000
3380 DISP "TYPE Y OR N"
3390 WAIT 3000
3400 DISP "IF MORE CHANGES, TYPE Y";
3410 INPUT E$
3420 IF E$="N" THEN 3640
```

```
3430 DISP "TO BEGIN NEW PAGE, TYPE Y";
3440 INPUT A$
3450 WAIT 3000
3460 DISP "TO CHANGE VALUE OF GERMINATION"
3470 WAIT 3000
3480 DISP "AND SURVIVAL RATE, TYPE Y";
3490 INPUT B$
3500 WAIT 3000
3510 DISP " TO CHANGE THE COST COMPONENTS,"
3520 WAIT 3000
3530 DISP "TYPE Y";
3540 INPUT C$
3550 WAIT 3000
3560 DISP "TO CHANGE VALUE OF REQUIRED"
3570 WAIT 3000
3580 DISP "NUMBER OF SEEDLINGS PER CELL"
3590 WAIT 3000
3600 DISP "IN OPTION 1, TYPE Y";
3610 INPUT D$
3620 WAIT 2000
3630 GOTO 560
3640 END
3620 WAIT 2000
3630 GOTO 560
3640 END
```

APPENDIX 2—Output of Sample Problems

```
                      OPTION ONE SOWINC STRATEGIES
                      ----------------------------

           EXTREME POINT SOLUTIONS         YHAT   EHAT   PENALTY  PENALTY
                                           PER    PER    PER      PER
  P   YBAR   X1      X2     X3      SBAR    CELL   CELL   M CELLS  M SDLGS

 0.7  0.80   0.00   1.00   0.00    2.00    0.91   0.49   11.01    12.10
 0.7  0.80   0.00   0.00   1.00    3.00    0.97   1.13   21.26    21.85
 0.7  0.80   0.63   0.00   0.37    1.73    0.80   0.41   10.26    12.83
 0.7  0.80   0.52   0.48   0.00    1.48    0.80   0.23    7.29     9.11


                      OPTION TWO SOWING STRATEGIES
                      ----------------------------

           EXTREME POINT SOLUTIONS         ZHAT   EHAT   PENALTY  PENALTY
                                           PER    PER    PER      PER
  P   YBAR   X1      X2     X3      SBAR    CELL   CELL   M CELLS  M SDLGS

 0.7  1.00   0.00   1.00   0.00    2.00    1.40   0.49   10.60     7.57
 0.7  1.00   0.00   0.00   1.00    3.00    2.10   1.13   21.14    10.07
 0.7  1.00   0.79   0.00   0.21    1.43    1.00   0.24    6.51     6.51
 0.7  1.00   0.57   0.43   0.00    1.43    1.00   0.21    5.99     5.99
```

PEPPER, WILLIAM D., and W. DOUGLAS HODGE.
1982. Computer can choose sowing strategies for containerized seedlings. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. SO-39, 12 p. South. For. Exp. Stn., New Orleans, La.

This paper presents an interactive computer program to help select an optimal sowing strategy to deal with the problem of blank containers in growing containerized seedlings.

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